FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

REPOSITIONING ENGINEERING MATERIALS RESEARCH AND INNOVATION FOR SUSTAINABLE DEVELOPMENT

By

Engr. Professor Oladiran Kamardeen Abubakre
M.Sc (Donetsk), Ph.D (Minna) R.Eng, MNSE, FNMS
Professor of Materials Engineering

INAUGURAL LECTURE SERIES 50

12TH JANUARY, 2017

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

REPOSITIONING ENGINEERING MATERIALS RESEARCH AND INNOVATION FOR SUSTAINABLE DEVELOPMENT

By

Engr. Professor Oladiran Kamardeen Abubakre
M.Sc (Donetsk), Ph.D (Minna) R.Eng, MNSE, FNMS
Professor of Materials Engineering

INAUGURAL LECTURE SERIES 50

12TH JANUARY, 2017

This 50th Inaugural Lecture was delivered under the Chairmanship of:

Professor M. A. Akanji, FNSMBM, FAS
Vice-Chancellor
Federal University of Technology, Minna

Published by:
University Seminar and Colloquium Committee
Federal University of Technology, Minna.

ISSN: 2550 - 7087

12th January, 2017

Design + Print:
Global Links Communications, Nigeria
✆: 08056074844, 07036446818

Engr. Professor Oladiran Kamardeen Abubakre
M.Sc (Donetsk), Ph.D (Minna) R.Eng, MNSE, FNMS
Professor of Materials Engineering

Preamble

Thanks, Adoration and Glorification be to Allah, the Almighty. We pray for His Blessings on all His messengers from the first of them - Adam through Musa, Isa (ASW) to the last of them all - Muhammad (SAW).

Majority of our audience are firm Believers in Supreme Being variously referred to as Allah, God, Olodumare, Chineke, Ubangidi, Soko. We are thus at home with His messages as found in the revealed scriptures. These scriptures give comprehensive accounts of creations in its diversity, variance and sequence. Suffice it is to quote one of the numerous account of creation in one of these revealed scriptures – Al – Qur'an.

"It is He who has created FOR YOU the entirety of what is on the earth ...." Q 2v29.

Thus God created the material world first in its full diversity and put them in the services of human being to be exploited to the extent and as far as his knowledge permits.

"O Company of jinn and mankind, if you are able to pass beyond the regions of the heavens and earth, then pass. You will not pass except by the Authority of Allah." Q55v33.

1.0 Introduction

My venture into engineering profession is more of God design rather than deliberate personal plan or scheming. I have always had my eyes on professional courses and had attempted studying Veterinary Science and Medicine before providence finally placed me in these noble professions of Engineering and Pedagogy.

Engineering: Engineering is a profession in which knowledge of mathematics and natural sciences is applied with judgment and responsibility to invent, design, construct, operate and maintain machines, structures and systems, utilizing the **materials** and forces of nature economically for the benefit of mankind (Olorunmaye, 2012).

Engineering which started with two broad divisions of Civil and Military/Mechanical has evolved into numerous branches which presently include Aerospace, Agricultural, Biomedical, Chemical, Civil, Computer, Electrical, Environment, Geological, Geomatics, Industrial and Manufacturing, Mechanical, Materials, Metallurgical, Mining, Mechatronics, Naval Architectural and Ocean, Nuclear, Petroleum, Software, System and Telecommunication Engineering. (Enibe, 2008)

All Engineering structures, devices and systems came into existence after careful and comprehensive design based on accurate analysis of forces. Numerous indeed are engineering fantasies and dreams but only those that could be supported by the existence of the appropriate materials will eventually come into existence and benefit mankind. Thus, Material Engineering occupies a unique place amidst other branches of Engineering.

Materials Engineering: The study of materials comprising metals, ceramics, polymers, semiconductors and composites, built on the scientific principles established in mathematics, physics and chemistry and applying them to various material-related problems or needs in society. It is also defined as the application of structure-property correlations, in designing or engineering the structure of a material to produce a predetermined set of properties

Considering the pioneering and the long standing status of the study of metals compare to other materials, Metallurgical Engineering is usually addressed in its own right while other materials find umbrella under Material Engineering.

The various options available to Materials engineers to specialize in, includes but not limited to, the following:

- Metallurgical engineering- specialization in metals, such as steel, aluminium and copper usually in alloyed form with additions of other elements to provide specific properties.

- Plastics engineering – the practice of developing and testing new plastics – known as polymers – for new applications.
- Ceramic engineering – the development of ceramic materials and the processes for making them into useful products – from high-temperature rocket nozzles to glass for LCD.
- Composites engineering – working in the development of materials with special, engineered properties for applications in aircraft, automobiles and related products.
- Semiconductor processing engineering – the practice of applying materials science and engineering principles to develop new microelectronic materials for computing, sensing and related applications.

Materials engineers develop, process, and test materials used to create a range of products, from computer chips and aircraft wings to golf clubs and snow skis. They work with metals, ceramics, plastics, composites, and other substances to create new materials that meet certain mechanical, electrical, and chemical requirements.

2.0 Materials - Milestone of Civilisation

The evolution of knowledge in harnessing the material world for the benefit of mankind gave rise to epoch of civilisation. Various classifications exist but for the purpose of this presentation, a five stage evolution of civilisation based on the advancement of human being in harnessing material endowment is adopted. The evolution of civilization base on prevailing materials has gone through the Stone Age, the Bronze Age, the Iron Age, the Steel Age, and the Silicon Age (Table 1). The typical material-based classification presumes that such materials must be product of human ingenuity, must cause huge impact globally, and the materials must subsist for considerable period (Bangwei and Yinjian, 2011).

The technological evolution of Nations also revolved around various prevailing engineering materials of the era: The Industrial Revolution (1740-1840) in the 18th Century England relied on Iron works. The boom in rail transportation (1850-1900) had Steel making as its backbone. The invention and subsequent spread in the use of Electricity and Internal Combustion Engine (1900-1950) was made possible courtesy of steel, aluminum and copper. Petrochemicals, Electronics, Computing, Aerospace industries flourished in 1950-1980 due to advanced knowledge in silicon, steel, light and heat resisting alloys. Mass production of affordable automobiles (Fordism) and mass production of goods in general (1930-1980) relied heavily on cheap steel (Obikwelu, 2014).

Table 1: Chronological Order of Evolution of Civilisation based on Materials (Bangwei and Yinjian, 2011)

Era	Stone Age	Bronze Age	Iron Age	Steel/Cement Age	Silicon Age
Duration	3 Million years	1800 years	3400 years	60 years	40 years
Span	3 Million BC - 3300BC	3300 - 1500BC	1500BC - 1900AC	1900 - 1960AC	1960 - 2000AC

It is worthwhile to preview the role of materials in the technological development of the previous civilisations to have a clear understanding of the challenges facing the Nation in terms of Material development. Attempt will be made to read the future trend of material development such that while we pay good attention to 'catching up' with the rest of the world, we also lay a good platform to become active participants in dictating the trend of technological evolution through our innovative contribution to the trending global material requirements.

2.1 The Early Civilisations – Stone Age to Iron Age

2.1.1: The Stone Age

The Stone Age derived its name from the major material used for tools and weapons at this early stage of human history. The Stone Age dates as far back as 3300 BC. The tools and weapons made of stone include axes, spear points, scrapers, and knives. The resort to stone was dictated by the challenges facing the early man who was left at the mercy of his environment. Thus to meet the basic needs of food and security, he has to rely on the material provision that would enable him to successfully hunt for his food and defend himself against the predators. A look at the early man, his tools and weapons is quite instructive. Wood, leather, stone and other materials were freely used by him, yet the era was referred to as Stone Age. In my opinion, two reasons may be responsible for this:

(i) Stone was the most crucial and most indispensable material in the bid of man to transform himself from Hunter-gatherer life to a sedentary existence.

(ii) The intellectual input in the conversion of stone to the appropriate tool was higher than in other materials.

The contribution of various parts of the globe to the Stone Age was wide spread. The earliest evidence of stone implements by Anthropologists was found in the rift valley of East Africa. One other early evidence of permanent settlement was found in Natufian culture in the present-day Israel. Archaeology findings at sites at Mount Carmel and Hula valley in Northern Israel revealed enormous quantity of gazelle bones, large number of flint sickle blades, arrow head, stone mortars, harpoons, hooks and net sinkers. This discovery attested to the dexterity of early man in hunting gazelle and processing it for food and his creative skill of fashioning out hunting, fishing, farming and food processing tools and equipment from stones.

Obsidian and Flint were the two types of naturally occurring stones formed as an extrusive igneous rock and were ready natural materials that were readily transformed into these various tools. The most advanced settlements were those, innovative enough to evolve a form of heat treatment that facilitates transformation of these stones into tools of choice.

Another interesting epoch of Stone Age was the discovery of the technology of firing clay. The Artisans at sites located in the present day Czech Republic fired a mixture of clay and loess in oven to obtain the first substance to be totally transformed by human through thermal processing. Ceramic – a remarkably transformed clay with water and hydroxyl molecules driven off upon heating was discovered at about 2600BC and yet remain one of the most influential material today and will still play a significant role in the foreseeable future. Ceramics was very strategic in the emergence of the first cities of the world in Mesopotamia – present day Iraq as it provided silos for storage of farm produce, vessels for water storage and clay plates for record keeping and documentation (Postgate, 1994).

One significant issue in the emergence of Mesopotamia as an independent city state is that the region is less endowed with obsidian and flint – the crucial natural resources of the era, yet it took over from other cities with more resource endowment through superior knowledge and more outstanding creativity of its leaders and artisans. Mesopotamian technology was a comprehensive, a non-documented process of training, organization, and recruitment of artisans and this gave it an edge over other previous city states and empires.

2.1.2 Bronze Age (3300 – 1500BC)

Early civilisations exploited readily available materials hence stone, bones, wood leather and clay were prominent in Stone Age. Metals can hardly be said to be readily available considering the insignificant fraction of major metals in the earth crust as shown in Table 2.

Table 2: Abundance of Metals in the Earth Crust

Element	Aluminium (Al)	Iron (Fe)	Lead (Pb)	Copper (Cu)	Zinc (Zn)	Tin (Sn)	Gold (Au)	*Silicon	*Oxygen
Abundance in %	8.13	5.00	0.013	0.0055	0.008	0.0002	1.0×10^{-7}	28.20	46.40

* - Selected non-metals for comparison.

Source: Allan Cottrell, 1995

Copper was the first prominent metals to be produced because of the relative ease with which its alloys could be obtained compared to alloys of Iron and Aluminum. Pure metals usually have less engineering significance than their alloys, thus when artisan discovered copper ores rich in tin and arsenic as impurities, it open ways for emergence of stronger materials for tools and weapons.

The Bronze age dates between 1500 – 3300 BC as different civilisation transits between Stone age to Bronze age at various times. The technology of bronze emerged in the Middle East (present day Iran) and spread to Sumer, Anatolia, Indus Valley and China (Asia). Bronze – a cast alloy of copper and tin provided improved materials for weapons for the Armies of the Bronze Age and luxury for the Rulers. Bronze attains its improved strength via solid solution strengthening and work hardening. It is also easy to cast due to its lower melting point than pure copper. Bronze on its discovery became the preferred material for the entire Bronze Age which spanned from about two thousand years while Bronze workers attained great expertise in casting monumental sculpture in various part of the world. The biblical narratives on Solomon temple, the Nok culture, the Benin and Ife bronze sculptures show the significant role of bronze in decorations and arts in all ages. Artisans also fashioned arrowheads, sickles, hammers, daggers and axes as weapons and farm implements far more rapidly and with superior properties than in previous materials era. The role of bronze in the emergence and growth of empires was reflected in the Bronze armour that reflects military superiority. The biblical narratives on David and Goliath and the plea of Saul to David to take advantage of his oversized armour dress clearly buttress this point. (1 Samuel 17:39)

The high level of technical expertise of Artisans of Bronze Age is reflected in the use of lost wax method to produce intricate crowns as found in Judean desert and much later in Ife and Benin Kingdom. This ancient technology has survived till date and is still in use in casting complex shapes and in high technology applications such as the production of single crystal blades for turbine engines (Lloyd, 1970).

Summarily:

i. Bronze shot into prominence in spite of centuries of working with copper because of its superior properties.
ii. A rival alloy – Copper – Arsenic did not receive prominence because of the health hazard and difficulty of maintaining predictable composition.
iii. Good number of Artisan paid the supreme price of death and chronic disease as a result of exposure to arsenic in the bid to give humanity superior materials.
iv. The smelting technology acquired in years of developing copper and bronze later served civilisation and propelled humanity into Iron Age.

2.1.3 Iron Age (1500BC – 1900AC)

Smelting is one unique technology Bronze Age bequeathed to subsequent civilisations. Developing and perfecting smelting of copper and bronze made it easier for artisans to tackle iron which has been out-of-reach in spite of its abundance (Table 2).

The Iron Age also provided a greater impetus to warfare through stronger war tools like sword, spears, arrow heads and cannons. The metallurgical skill of various empires is synonymous to their ability to defend themselves and expand their territories for material gain at the expense of others. Thus special attentions are usually paid by such empires to their blacksmiths who form the power house of their military strength.

Middle East is the birthplace of the Iron Age. The Hittites in Anatolia were the first people to produce iron at about 1200 BC. Although in its pure form, iron is inferior to bronze strength-wise, but being the latest achievement of technology, it gained immediate appeal and value. It sometimes served as precious gift from one Monarch to the other.

To substantially strengthen iron, smiths had to form alloy containing approximately 0.9 percent carbon. This was achieved through a long, complex, and unpredictable process route shown in Figure 1. Considering the theoretical knowledge available today, one marvels at the skill of the Smith to correctly establish and control the multitude of parameters that affected the production process.

It is thus not surprising that there were incidences of catastrophic failure of these products as recorded in the blast that killed King James II of England in 1460 and the huge cannon designed to attack the wall of Constantinople which cracked after the first firing in 1453.

Figure 1: The Complex and Unpredictable Process of Producing Iron-alloy from Ore

The considerable improvement in iron when reheated in furnace with charcoal (known today as case hardening) set the stage for iron replacement of bronze weapons, agricultural implements and tools. Innovation gave birth to iron and continued innovation brought dramatic changes in its price and status from being a precious metal in possession of the Kings to a common engineering material, plummeting the price of iron by a factor of about 80,000.

Iron was heated and hammered (forging) but never melted due to its high melting point (1528°C) until the Chinese developed a furnace hot enough to melt iron, enabling them to produce the world's first cast iron – an event traditionally dated to 513 BC. It is noteworthy that it took almost a thousand years from inception of Iron Age to the production of first liquid iron. The Chinese were about a thousand years ahead of the western world in the production of liquid iron. The first iron foundry in England dates only from 1161 AD (Wertime and Muhly, 1980).

While the term Iron Age was generally used in describing this era, the products from Smiths include steel and cast iron. Wrought iron however, was the most prominent form of Iron throughout most of the Iron Age. This era has the largest span compared to other eras of civilisation. It also dovetailed into the preceding and subsequent eras.

2.1.4 Steel Age

Steel has been known since the iron era but their applications were limited to thin implements such as swords and daggers because of the complex process of infusing carbon into iron. The first industrial revolution thrived on the use of cast and wrought iron. The busy rails in Britain in mid-nineteenth century had to be rotated every three to six months because of the changing shape as the locomotives rolled over them. Boilers wall for steam engines were also quite thick and heavy. All these shortcomings were promptly addressed with the invention of affordable steel.

Significant role in making steel accessible and affordable was played by the inventions of Henry Bessemer, Robert Mushet (UK), Karl Siemens (Germany), William Kelly in Kentucky (US) in mid-19th Century and later by Austrian inventors of Linz-Donawitz Process. They devised processes to reduce the carbon content of pig iron by burning off the excess carbon in the molten metal with a blast of hot air. This effectively takes care of manganese, silicon, phosphorus and other impurities.

The innovations above heralded the new era of mass production of cheap steel which revolutionized our civilisation. It opened way for production of cheap and abundant steel from which railroads, oil and gas pipelines, refineries, power plants, power lines, assembly lines, skyscrapers, elevators, subways, bridges, reinforced concrete, automobiles, trucks, buses, trolleys, refrigerators, washing machines, clothes dryers, dishwashers, nails, screws, bolts, nuts, needles, wire, watches, clocks, canned food, battleships, aircraft carriers, oil tankers, ocean freighters, shipping containers, cranes, bulldozers, tractors, farm implements, fences, knives, forks, spoons, scissors, razors, surgical instruments, ball-bearings, turbines, drill bits, saws, and tools of every sort are produced (Spoerl, 2000). From the array of product listed, production of steel is synonymous with technological advancement. The various countries that contributed significantly in the inventions that revolutionised steel production took their turns in leading the world.

Inventions usually emerge from dynamic interplay between needs of the times, the creativity of the people and the appropriate government policy. Great Britain became a leading economy of her era courtesy of series of needs that were well articulated and supported by appropriate government policies. This combination drove the creative minds of the Inventors to produce steam engine and other machines that characterizes the first industrial revolution. Events that catapulted Great Britain ahead of other economies could be chronicled as follow:

- There was need to feed huge demand of iron production with coal. This motivated the innovations in coal mining technology in Britain.
- The need for mechanisation of coal mining activities as mines get deeper and deeper resulted in the invention of the steam engine.

- The need for inexpensive transportation to bring coal and iron together from mines to smelting facilities created pressure for cheap transportation and thus boost rail transportation system.
- The government's deliberate policy encouraged private capital to fund the huge investment requirement of mining and iron industry.

Steel production grew astronomically in Britain and with her leading role in the various inventions of industrial revolution era; she became the world leader for centuries. In early twentieth century, steel production in United State grew exponentially due to vast quantities of iron ore in Minnesota. With similar boost in steel production in Germany, Germany and US reduced the Britain contribution to global steel output from 70% to 30%, thus successfully ending Britain dominance. United States thus shot into the lead of Steel technology.

Towards the end of this century, the United States fell behind in steel technology as innovation and world leadership shifted to Japan. The history of stone, bronze, iron and steel illustrates the advantages that accrue to those who relentlessly pursue technological superiority, and how quickly the mantle of innovation and consequently world leadership passes from one country to another.

2.1.5 Africa - From the Stone Age to Steel Age

Sub-Saharan Africa appeared to have jumped Bronze Age, evolving to Iron Age directly from Stone Age. It has earlier been asserted that the earliest evidence of stone implements by Anthropologist was found in the rift valley of East Africa. Jos Plateau in Nigeria and Lake Victoria in Southern part of Africa were home to the earliest evidence of iron-working in sub-Sahara Africa. Archaeological discovery of 13 iron smelting furnaces at Taruga and Samun Dukiya and iron artefacts that included hooks, bracelets, knives, arrowheads and spearheads are evidences of the Nok culture in central Nigeria. It appeared about 1000 BC and by 500 BC, smelting and forging iron for tools were well-developed. Similarly, there are archaeological records of Iron works at settlements around Nsukka, Enugu State where Iron smelting was practiced as early as 765-120 BC (Obikwelu, 2014). In Sub-Sahara Africa, farming and metallurgy seem to be related to each other. Pottery was also well developed in this era.

The African continent contributed significantly to stone and iron age. The oldest relic of stone-age was found in the rift valley of East Africa while evidence of advanced black smithing abounds in various historical museums showing the valour of African warriors and signifying their contribution to Iron-age. The gap between Africa and the rest of the world started to widen with the advent of steel age. This era coincided with the era of boom in slave trade activities and may possibly lead to a simplified deduction of blaming slave trade for slow pace of material development in Africa. A critical look at the events of the era reveals the possibility of an alternative postulate. Material development up till the end of iron era was purely an art and specialised skill based on training and experience that is often transferred from one generation to the other. With the advent of industrial revolution, research in science and innovation started to play crucial role in material development. While the scientific basis of material production was hardly known to the artisans of iron-age, the invention of Henry Bessemer and the vital and complementary contribution of others to steel age have significant scientific input. Thus Africa started to lag behind when material development transformed from art to scientific endeavour. The slow pace of infusion of scientific approach to material development in the continent is possibly responsible for the widening gap between Africa and the rest of the world in technological development.

Consequently, the dexterity of Massaga (Bida, Niger State) brass work and glasswork artisans, the beauty and creativity of Benin bronze artisans, the valour of Blacksmiths in many parts of

Nigeria and Africa may therefore remain object of tourist attraction, embedded in superstitious belief, and with no significant contribution to industrial development of the Nation. The art and skill of these great artisans must be enriched with science and innovation and the practice must transform from the realm of metaphysics to scientific endeavour for meaningful contribution to National Industrial development.

2.2 Steel Development and Developmental Indices

2.2.1 Steel and Technological Advancement

In spite of the fact that Steel era was supposed to have ended in the 60s, the dovetailing of steel era into preceding and subsequent era made steel production and consumption a relevant parameter in today's discussion of technological advancement. The wide range of products made from steel is such that any nation that is not self-sufficient in its production will remain in the periphery of technological development.

The declining per-capital consumption and production of steel in developed economies as noticed in recent years is an affirmation of the end of steel era. While the decline in production and consumption characterises European and American economies, the Asian economies with the exception of Japan is witnessing growth in these parameters (Figure 2). This buttresses the age long assertion that material eras vary from one zone of the planet to the other.

Very few African countries feature in the list of World Steel producers while the per capita consumption is less than 50kg in Africa. The Continent is expected to focus and stimulate the growth in both steel production and consumption following the trend of developing economies of Asia and South America.

2.2.2 Steel and Developmental Indices

Gross Domestic Product (GDP) has been severely criticised for not sufficiently indicating the strength or advancement of

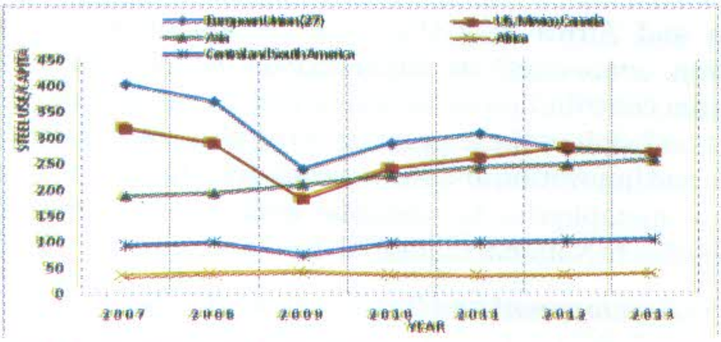


Figure 2: Relative Growth/Decline in Steel Use per Capita in various Continents. *(Source: World Steel Yearbook)*

economies (Abubakre, 2007). It portrays more of growth in economic activities of Nations. Human Development Index (HDI) is often preferred to GDP by virtue of its more encompassing nature and is favoured due to its reflection of socio-economic development. The GDP data from World Bank and IMF showed insignificant variance and hence could be used interchangeably without affecting the conclusion considerably.

A cursory look at the 25 top economies based on GDP ranking showed a good coherence between GDP, Steel production and Steel consumption. The exceptions are Australia, Indonesia and Saudi Arabia with low steel consumption. Switzerland not only ranked low in Steel consumption, but ranked a distant 44th in terms of production. Nigeria's situation is quite peculiar as it is the only nation in the pack of 25 that showed very low consumption (less than 50kg) and extremely low ranking in term of production.

Juxtaposing GDP and HDI revealed that nearly all the top ranked 25 countries by GDP were classified as nations with 'Very High' and 'High' HDI. India and Indonesia are exceptions as they were placed among the countries with 'Medium' HDI. Not only was Nigeria the only nation in the pack of 25 classified among the 'Low' HDI nations, She was also placed at a distant 152nd position in HDI (Table 3).

It could be asserted that, not only do our steel development indices question the veracity of our GDP placement, a more encompassing development Index equally aligns with the position that GDP may signify a growth in the economy although such growth has not significantly transformed into development in Nigerian situation.

Table 3: Ranking of World Economies based on GDP and HDI

Ranking of World Economies based on GDP			Steel Production		Per Capital Consumption		HDI
W.B. Rank	Country	GDP (Millions of US$)	Ranking	Production (million tonnes)	Ranking	Consumption (kg)	
1	United States	16,768,100	3	87.0	14	300.2	V. High
2	China	9,240,270	1	779	5	515.1	V. High
3	Japan	4,919,563	2	110.6	3	516.8	V. High
4	Germany	3,730,261	7	42.6	6	460.2	V. High
5	France	2,806,428	14	15.7	17	196.0	V. High
6	U. Kingdom	2,678,455	18	11.9	23	127.7	V. High
7	Brazil	2,245,673	9	34.2	22	131.9	V. High
8	Italy	2,149,485	11	24.1	12	354.3	High
9	Russia	2,096,777	6	69.4	13	301.9	V. High
10	India	1,876,797	4	81.2	29	57.8	Medium
11	Canada	1,826,769	17	12.4	7	425.0	V. High
12	Australia	1,560,372	30	4.7	>30	<50	V. High
13	Spain	1,393,040	16	13.7	16	221.0	V. High
14	South Korea	1,304,554	5	66.0	1	1075.4	V. High
15	Mexico	1,260,915	13	18.2	20	158.1	High
16	Indonesia	868,346	38	2.6	>30	<50	Medium
17	Netherlands	853,539	24	6.7	18	205.8	V. High
18	Turkey	822,135	8	34.7	8	415.4	High
19	Saudi Arabia	748,450	26	5.4	>30	<50	V. High
20	Switzerland	685,434	44	<2.0	>30	<50	V. High
21	Argentina	609,889	28	5.2	25	122.1	V. High
22	Sweden	579,680	32	4.4	11	368.8	V. High
23	Poland	525,866	19	8.0	15	266.9	V. High
24	Belgium	524,806	22	7.1	10	378.1	V. High
25	Nigeria	521,803	>50	<1.0	>30	<50	Low (152nd)

The National developmental agenda is adequately captured in the Vision 20:2020 document. To actualise the dream of Nigeria to join the comity of developed Nations, Nigeria must produce 12 - 17 Million tonnes of steel to attain the 20th position by 2020 (based on the 20:2020 vision documents, apparent Steel Consumption of 100kgand the statistics on importation of steel and allied products). Thus, with the current production capacity of 3 million tonnes contributed mainly by private firms operating scrap remelting facilities, Nigeria needs to quadruple her steel production capacity to attain her vision 20:2020. The challenge is presently not only in the quantity of production, scrap remelting (which is the preoccupation of the private steel producers) cannot be regarded as steel production by any serious, development minded Nations.

2.3 Silicon Age

Materials science and engineering have exploited the diversity of material endowment from the Stone Age to the present. In the half of this century, the synergy of physical science, engineering and technology have combined to bring silicon and its oxides to serve humanity. This brings to a halt, the dominance of metal as materials of civilisation and thus brings Semi-conductors to the forefront. Living in today's world without semi-conductors products like transistors, diodes, solar cells, computers, and all their derivatives is simply unimaginable.

The enabling environment in USA that facilitated the emergence of silicon age includes:

- Government Policy that required the attainment of vital National Goal – miniaturisation of computing and control system of spacecraft for NASA projects.
- Strong commitment to the government policy thrust leading to establishment of good number of dedicated laboratories for material research.
- Existence of privately driven research establishment / companies for commercialisation of innovative concept such as Intel, Texas Instrument and others.

2.3.1 Silicon Switches

The "transistor effect" was discovered in Germanium by John Bardeen, Walter Brattain and William Shockley in December 1947. The two limiting factors in the use of germanium transistors are the temperature and high chemical activity limitations. Silicon became a suitable alternative because of higher energy gap of 1.1 eV which made it suitable for higher temperature environment. However, silicon is also chemically reactive and thus needed to be coated with a very thin but impervious layer of silicon dioxide.

The earliest computer such as Electronic Numerical Integrator and Computer (ENIAC) operated on mechanical switches. ENIAC was capable of performing 333 multiplication per second but required about 6,000 switches covering three walls as memory and took days to reprogramme. The advent of silicon switches was a critical turning point that heralded the era of miniaturization of computers. It also heralded the new era of Smart Materials.

Robert Noyce considered the isolative properties of silicon dioxide and used it to isolate transistor, resistor and capacitor in electronic circuit formed on the same silicon chip. Addition of dopants to special sites allowed fabrication of individual electronic component. While one dopant produced a transistor, another produced a resistor. Metal lines printed directly on the surface of silicon dioxide coated chips were used to join individual transistor thus giving birth to integrated circuit which is the heart of modern day computer.

2.3.2 Integrated Circuits

The impetus for the development of integrated circuits was given by Minuteman missile program and the Apollo space mission. The programme required miniaturized computers on-board the rockets and lunar modules. The early chips were developed at huge cost for military and space programme illustrating how defense-related needs often drive and pay for revolutionary advances in technology. The first Noyce microchip in 1964 contains 10 circuits being placed on one chip. By 1975, 32,000 circuits, creating 32Kb memory chips were available and presently, several millions of transistors can be fabricated on a single chip. While Robert Noyce and Jack Kilby are co-inventors of integrated circuits, Ted Hoff put all functions of a computer on a single silicon chip with separate chips holding the input-output and programme components. This gave birth to the first microprocessor that contained more than 2000 transistor on a chip measuring 3.5mm by 4.5mm and as powerful as the ENIACs of 50s and 60s. This invention started a silicon revolution with the chips becoming smaller and cheaper at such unpredictably alarming rate.

Moore's Law - proposed by Gordon Moore, co-founder of Intel in 1965, says that the number of components on a chip of a given size will roughly doubles every 18 months. Moore predicted that by 1975 a typical chip would contain 65,000 components. Moore's Law had held steady for the past four decades and presently some chips contain as many as 65 million components. Miniaturised computers are presently found in refrigerators, automotive electronic ignition system, microwave ovens. In fifty years, the performance of computers has improved by a factor of one million, thanks to silicon chips (Stephen, 2011).

Silicon revolution is at the heart of information age. It transforms the leading economies into knowledge based economy. California – the host state to Silicon Valley is just one of the 50 states in USA and is presently ranked the 6th strongest economy of the world. In the words of Al-Gore – one time Vice President of USA – 'Information revolution in the last quarter of the twentieth century transformed economic output by substituting ingenuity for raw materials. America economy grew by 300% from 1950 to 2000 while the gross tonnage remain the same' (Al-Gore, 2007).The list of the richest individuals in the world shows majority has connection with information age revolution. In Nigeria, the list is populated by oil block owners and speculators.

2.4 Africa in Silicon Age

The contribution of Africa to silicon age in terms of inventions and manufacturing is minimal. The information age stands on a tripod of silicon revolution, optical fiber development and world wide web/internet. While African nations are good consumers of information age products, the continent's contribution to design, development and innovations in hardware is very insignificant. African companies thrive in trading and assembling of hardware, networking and software development. In the best cases, Nigerians in diaspora have floated and ran very innovative and successful IT companies which they sold to make huge fortune from apps development (Guardian Newspaper, 12th December, 2016). Companies abide in Nigeria making impressive contribution to Information age through development of Mobile Apps and software as attested to by the recent visit of Mark Zuckerberg to Nigeria (Okonji, 2016).

The contribution of African continent to research and development in information technology is modest judging by scientific publication emanating from Africa. However, the level of innovative product originating from Africa and finding its way to market is quite insignificant.

In conclusion, Nigeria must reappraise her contribution to Steel and Silicon age. Conscious effort must be made to remove all the impediments on the way of developing viable steel industry and making the Nation self-sufficient in various form of steel product. The recent exclusion of 41 items from concessional foreign exchange allocation could be a good stimulant for self-sufficiency in steel production. Similarly, attention should henceforth not be limited to software and mobile apps development, deliberate government policy to incentivize hardware and innovative component development.

3.0 The Current Trend and Future Perspective

The tempo of development has been dependent upon and will, in the foreseeable future, continue to depend on the speed of evolution and development of new and novel materials to meet mankind needs. Few of the current trend that will play significant role in the nomenclature of the next material era are nanomaterials, smart materials, biomimicry, biodegradable materials, plastics and ceramics composites and high strength steel.

3.1 Nanomaterials

Professor Richard Smalley - a Nobel Prize Winner in Chemistry opined that "the impact of nanotechnology on health, wealth and the standard of living for people will be at least the equivalent of the combined influences of microelectronics, medical imaging, computer-aided engineering and man-made polymers in previous century." The first clear vision of nanotechnology was laid out in 1959 by Richard Feynman in a talk to the American Physical Society titled 'There's Plenty of Room at the Bottom.' He contemplated on the problem of manipulating and controlling things on a small scale - scale of atoms and molecules. He ended his talk by offering two prizes of a thousand dollars each to anyone who could either make an electric motor, no bigger than 0.04mm in any dimension or write down the information on a page of a book in an area scaled down by a factor of 1/25,000. Feynman wrongly anticipated that his money would be safe as he underestimated the existing skills of engineers who produced the micro-electric motor just few months later (Feynman, 1960).

The US Government clearly believes in great potential of Nanotechnology and is investing enormous resources in nanotechnology research and development. As far back as 2002, United States spent approximately $600 million while Japan spending was about $750 million on nanotechnology research.

Some Nano technological products already in the market include: Sunscreens, which absorb ultraviolet light and protect our skin while remaining transparent. Self-cleaning glass or ceramic tiles where nanoparticles use the energy of the sun's ultraviolet rays to burn up dirt on the glass or ceramic surface and help rain water to spread evenly on the surface and wash dirt away. Similar spray-on coating could be used to make clothing and shoes that repel both water and dirt thus making them both waterproof and self-cleaning.

Nanomaterials are set to revolutionise various aspect of human endeavour including energy, water purification, healthcare, mining, defence and others.

Nanotechnology in Energy

Nanomaterials have many promising applications in energy-related areas. Graphene - an atomic-scale honeycomb lattice made of carbon atoms has the capability to improve energy capacity and charge rate in rechargeable batteries. It has the potential to produce superior super capacitors for energy storage. The graphene electrodes are quite promising for making inexpensive, lightweight and flexible solar cells. Fuel Cells offer enormous potential for rural electricity generation.

Nanotechnology in water purification

Nanotechnology presents a cost-saving and effective way to solve water purification challenges. Nanomaterials can be designed with specific pore sizes and enhanced surface areas to filter unwanted pollutants such as heavy metals or biological toxins. Various nanoparticles are capable of degrading organic and biological pollutants. Different membranes and filters based on carbon nanotubes, Nano porous ceramics, magnetite, silver and titanium oxide nanoparticles could also reduce water-borne diseases.

Nanotechnology in Health Delivery and Diagnostics

Nanotechnology holds the key to revolutionise health care in both diagnostic and treatment aspect. In Diagnostics, Nanotech promises quick, early and accurate detection of diseases through Point-of Care test kits; a hand-held kits that could be used to test for viruses, bacteria and hormones. The kits could be used quickly to test for infectious diseases such as malaria, cholera, HIV/Aids, STD and cancer. In Biomedical Imaging, gold and silver nanoparticles have optical properties which make them effective contrasting agent for detection of diseased cells such as tumour sites.

In *Therapeutics or Treatment,* targeted drug delivery nanotechnology system can recognise diseased cells and deliver drugs to the affected areas to combat cancerous tumours without affecting healthy cells. Nanoparticles can target inhibition of fat growth to tackle obesity. Slow-Release Drug therapy using Nano-sized biodegradable polymer capsules containing drugs could effectively be taken up by body's cells. The slow release of drug reduces the dosage and increases the prescription compliance, thus decreasing chances of drug resistance (Gonzalez-Fernandez, 2012).

Nanotechnology in Defence

Nanotechnology research has contributed enormously to defence industry. The Nano Teflon - a water-proof and bullet-proof army tactical vest has been developed through nanotechnology. Nanospy is a Nano air vehicle/Nano hummingbird that has enormous surveillance capability. It is another nanoproduct of significance in defence. Chemical and biological nanosensors that are capable of detecting chemical and biological contaminant is a blessing from nanotechnology to combat chemical and biological warfare. Electrochromic camouflage that enables combatant to blend perfectly with his/her surroundings - going invisible is another novelty from nanotechnology to defence industry (Bankole *et. al.,* 2015).

Nanotechnology is not a single area of science with a single or unified objective, rather, it is almost a new kind of technological philosophy, a new way of doing things and thus stands a very good chance of giving nomenclature to the next age.

3.2 Nature-Inspired Materials

Thinkers and Scientists of the old drew a lot of inspiration for their invention from the natural forces and phenomena. The development of aviation and the crude imitation of birds in evolving the first planes attested to the age long tradition of learning from the nature. The systematic way of capturing nature's creativity, creating the scientific basis and deploying it to create new items or solve a particular problem transform 'nature imitation' froman art to a scientific endeavour named Biomimickry. Some of the materials that evolved from human study and mimicking of the nature include Velcro, Bullet train, Shark skin, Harvesters of desert fog, Nature water filter, Experimental fish car, Watercube, Fishy wind farm, Candy-coated vaccine and Fireflight lightbulb.

Velcro: After a hunting trip in the Alps in 1941, Swiss engineer George de Mestral's dog was covered in burdock burrs. Mestral put one of these burrs under his microscope and discovered a simple design of hooks that nimbly attached to fur and socks. After years of experimentation, he invented Velcro — and earned U.S. Patent in October 1952. This invention is probably the best-known and most commercially successful instance of biomimicry.

Spider Silk: Spider silk has been shown to have more tensile strength than steel and Kevlar. It has enormous ductility such that it can stretch 140 percent of its length without breaking and remains flexible even in extreme cold. It is also light in weight that 0.5 kg of spider web could form a single strand long enough to stretch around the equator. Scientists successfully identified the two genes in spider's DNA that makes silk. They have copied the genes and spliced it into DNA of goat so that they will make spider-like protein in their milk.

Snake Skin: The snake's skin provides a vital useful hint in designing machine and system with reduced friction in forward direction while creating enough on the rear of the scale to let the snake propel forward. Snakes and similar reptiles have evolved a coating of scales built to maximize resistance against wear. The good friction control and durability could find a use in high-end automotive engineering, such as Formula One race cars, or in the coming generation of search-and-rescue and exploration robots modelled off snakes. They could equally be used as coatings in mechanical parts and sensitive sensors such as accelerometers.

Prof Leonard Daniel of MIT and Christian Greiner from Karlsruhe Institute of Technology in Germany asserted that the textured surface created by mimicking snake and lizard have a reduced sliding friction force as much as 40 percent in tests. The friction reduction disappeared when the textured surfaces were put into contact with oil, meaning that they will only work in dry, sandy environments, like where snakes live.

Shinkansen Bullet Train: High-speed trains can literally cause headaches with the enormity of noise pollution particularly when the trains emerge from tunnels. As they drive through, air pressure builds up in waves and, when the nose emerges, can produce a shotgun-like thunderclap heard from a quarter mile. Eiji Nakatsu, a bird-watching engineer at the Japanese rail company JR-West, in the 1990s took inspiration from the kingfisher, a fish-eating fowl that creates barely a ripple when it darts into water in search of a meal. The train's redesigned nose - a 50-foot-long steel kingfisher beak - didn't just solve the noise problem; but reduced power used and enabled faster speeds.

3.3 Smart Materials

Smart materials are materials that have a property that can be significantly changed in a controlled way by external stimuli. The external stimulus causing the change in the materials properties may include stress, light intensity, temperature change, moisture, pH, electric potential difference and magnetic field.

The smart materials change in response to changing conditions in their surroundings or by the application of other direct influences. The induced change in the property of the smart material might be in its electrical behaviour, its mechanical-structural properties, optical and magnetic behaviour. Any of these properties change the way the material functions in response to the stimulus.

In a nutshell, smart materials can change their state, and therefore their properties, in response to an external stimulus.

There is now a huge variety of smart materials with different special properties that make a particular material well suited to a specific use.

Smart materials include Chromogenic Materials, Shape Memory Alloys, Shape Memory Polymers, High performance polymers like KEVLAR and many others.

3.4 The Features of Future Materials

The advance in material characterisation equipment has enabled an increasing element of rational design to be incorporated into materials innovation. Materials can now be designed and tailored to particular tasks. These enhanced technical capabilities are also shrinking the size scales at which engineering can be conducted.

Materials science has experienced a trend away from structural materials towards functional ones: from materials that perform some passive structural role (generally supporting a heavy load) to ones that perform some active function, such as generating an electrical current or closing a valve. Functional materials will do things previously unimaginable; emit light, swell and contract when prompted, and stimulate bone growth or release drugs.

In the near future, materials discovery and invention will gradually take the back stage while material design for specific job will become the vogue. Components of functional materials will be rationally selected and assembled for specific functions. Even steels are becoming highly designed materials, with carefully blended compositions to suit different roles.

4.0 Assessment of Nigeria's readiness for the next Material Age

Activities of nations as they relate to innovations in science and technologies could be judged using the under listed indicators:

- National expenditures on research and development
- Federal government scientific activities

- Personnel working in science and technology
- Research output (citations)
- Patented inventions.

Same indicators will be used to assess the readiness of Nigeria as a Nation to catch up with her contemporaries in Material development and play active role in the innovation of materials for the next age.

4.1 National expenditures on research and development

A sectoral analysis of Nigerian budget in recent years gives an insight into how critical research and development is to our policy formulators. While various authors have put the Nigerian expenditure on Science and Technology at 0.2% of the budget, analysis of 5 year appropriation reveals an average of about 0.7% allocation to Science and Technology Ministry – the key Ministry that drives National research, development and innovation (2012-2016 Appropriation Bill). Other Ministries that contribute to funding research in Science and Technology include Ministries of Agriculture, Petroleum, Communication and Education. While the percentage expenditure to the Ministry falls short of 2% recommended for meaningful technological development of a nation, the situation is worsen by the fact that the bulk of the allocation is gulped by recurrent expenses, thus leaving a dismal average percentage of 0.23% allocation to the core activities of the Ministry.

It is noteworthy that Nigeria did not make the list of the 40 countries spending the most on Research and Development. Only South Africa featured on the list, ranking 29th. The modest spending by the Nation was tilted more in favour of recurrent expenditure rather than capital expenditure.

The considerable rise in the budgetary allocation in 2016 and the relative improvement in the capital/recurrent ratio in favour of capital expenditure is a possible indication of the desire to correct the anomaly of the past years.

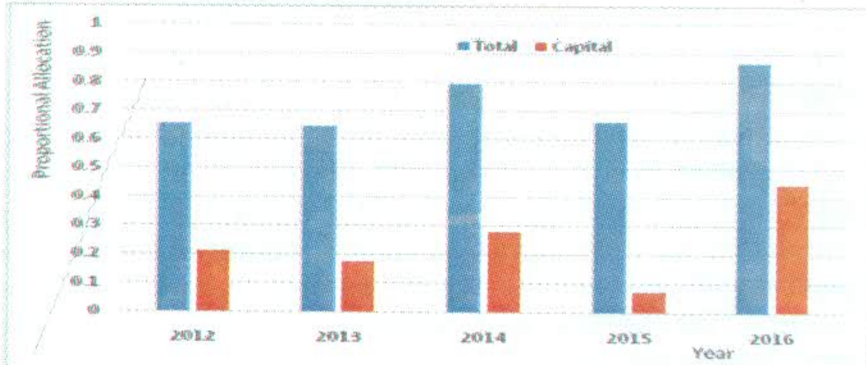


Fig. 3a: Proportional Allocation to Ministry of Science and Technology

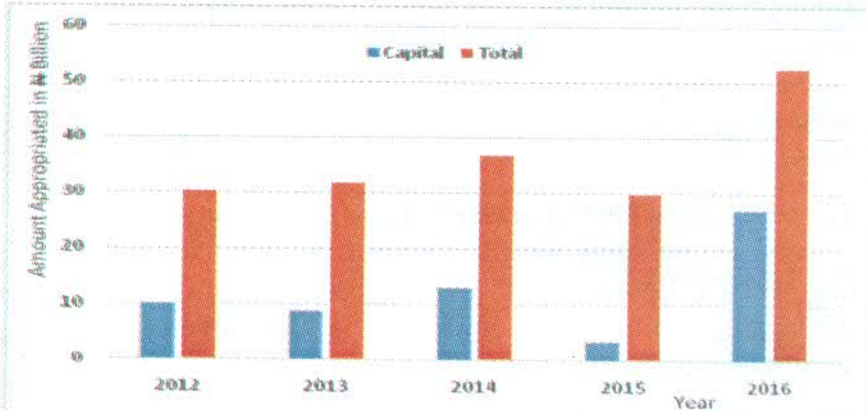


Figure 3b: Appropriation to Ministry of Science and Technology in N billion

4.2 Federal government scientific activities

The federal government research activities could better be described as uncoordinated as it lacks policy direction and fund commitment towards the realisation of National goal. The large number of research institutes with dismal budgetary provisions, lack of National priority mandate and consequently little result to show over the years for their existence is a clear indication that the Federal government and other tiers of government are yet to evolve a clear direction for research activities. One easily recall the role US government played in the evolution of Silicon age and the role earlier played by UK government in emergence of Steel age.

Nigeria may soon be on the path of joining the League of Nations committed to development and be repositioned to take its rightful place in Africa, if the pronouncement of this present government is anything to go by. The Minister of Science and Technology, Dr. Ogbonnaya Onu while speaking on behalf of the government asserted the regime resolve to revisit National Science, Technology and Innovation Policy, which was formulated about 30 years ago but was never implemented. National Research and Innovation Fund will be created with appropriate legislative backing and 1% of the GDP will be dedicated to the Fund. This is expected to solve the problems of under funding of research and development in the science, technology and innovation *(The Nation Newspaper, 26th July, 2016).*

4.3 Personnel working in science and technology

In spite of the huge population and the astronomical rise in Engineering, Research and Development personnel, Nigeria is still lagging behind many countries. The statistics on engineering personnel is reflected in Table 4:

Table 4: Population of Engineering Personnel in Nigeria registered with COREN

Categories	Population	No per 1000 populace
Engineers	63,000	0.37
Engineering Technologist	9,000	0.05
Technicians	6,000	0.03
Craftsmen	6500	0.03

Considering the total personnel in Research and Development in the various scientific field, Nigeria ranked distant 43rd position in the world behind such African countries like Morocco, South Africa and Egypt as shown in Table 5.

Table 5: Research and Development Personnel in Countries of the World

Rank	Countries	R&D personnel	Rank	Countries	R&D personnel	Rank	Countries	R&D personnel
1	China	1,736,155	16	Poland	75,309	31	South Africa	31,352
2	Russian Federation	912,291	17	Mexico	70,293	32	Romania	28,977
3	Japan	912,202	18	Pakistan	69,619	33	Hungary	25,954
4	Germany	506,450	19	Turkey	63,377	34	Hong Kong	23,644
5	France	375,235	20	Belgium	57,963	35	Morocco	23,201
6	United Kingdom	343,855	21	Finland	56,243	36	New Zealand	21,000
7	Rep. of Korea	269,409	22	Austria	53,252	37	Ireland	18,157
8	Canada	248,640	23	Argentina	53,187	38	Bulgaria	16,940
9	Brazil	214,349	24	Czech Rep	49,192	39	Serbia	15,921
10	Italy	208,376	25	Denmark	46,897	40	Slovakia	15,421
11	Spain	201,108	26	Thailand	42,624	41	Iraq	13,563
12	Ukraine	132,926	27	Greece	35,531	42	Lithuania	12,480
13	Netherlands	93788	28	Portugal	35334	43	Nigeria	11,330
14	Egypt	79658	29	Norway	33635	44	Chile	11,024
15	Sweden	75318	30	Singapore	32198	45	Slovenia	10,369

4.5 Research output (citations)

In the last decade, Nigeria has improved considerably in her research activities considering the increase in the number of the state-of-the art facilities scattered around the country in Universities and Research Institutions. The access to internet facilities has equally improved tremendously from the days when Researchers travelled to NUC for cheap access to internet. Consequent upon this, Nigerian Researchers have made the best of the situation by increasing the number of scientific publications in reputable and high impact factor journals. Nigerian Universities have also keyed into webometric ranking and featured prominently among the leading Universities in Africa, although we are still far from making impressive ranking globally. Nigeria ranked high among African nations in Webometric presence, Scientific and Engineering publications and publications in Biotechnology, Nanotechnology and other emerging scientific fields (Table 6).

Table 6: Continental Ranking in Publications of Engineering and Nanotechnology Publications

Rank	Country	General Engineering		Nanotechnology Publications
1	South Africa	17,605	South Africa	9,664
2	Algeria	12,103	Algeria	8,626
3	Tunisia	10,674	Tunisia	7,100
4	Nigeria	5,016	Nigeria	3,746
5	Morocco	4,936	Morocco	2,330
6	Libya	875	Libya	451
7	Ghana	703	Ghana	336
8	Cameroon	613	Mauritius	320
9	Sudan	575	Sudan	311
10	Kenya	525	Kenya	279
17	Mauritius	275		

4.6 Patented inventions

Another indicator is the degree of patented inventions. The protection and enforcement of intellectual property rights is central to attracting foreign direct investment and increased revenue (Uche, 2012). Patent and intellectual property (IP) in Engineering Research and innovative technology was investigated by the trend, number, and indices of registered patents over the years using the World Intellectual Property Organization (WIPO) database. The WIPO is one of the 17 specialized agencies of the United Nations which was created in 1967 "to encourage creative activity, to promote the protection of intellectual property throughout the world." A 2015 WIPO global innovation index ranked the innovation performance of over 140 countries by region where each country was scored using 79 indicators. The top performers taking the lead in innovation in the Sub-Saharan Africa were Mauritius, South Africa, and Senegal. By income group, WIPO identified top innovators as shown in (Table 7).

Table 7: Global Ranking of Nations based on Global Innovation Index

World Ranking		African Ranking	
Ranking	Country	Ranking	Countries
1	Switzerland	1	South Africa
2	Sweden	2	Tunisia
3	United Kingdom	3	Kenya
4	U.S.A.	4	Rwanda
5	Finland	5	Mozambique
6	Singapore	6	Botswana
7	Ireland	7	Namibia
8	Denmark	8	Malawi
9	Netherlands	9	Uganda
10	Germany	10	Ghana
11	Korea	11	Tanzania
12	Luxembourg	12	Senegal
13	Iceland	13	Egypt
14	Hong Kong	14	Côte d'Ivoire
15	Canada	15	Ethiopia
16	Japan	16	Madagascar
17	New Zealand	17	Mali
18	France	18	Algeria
19	Australia	19	Nigeria
20	Austria	20	Cameroon

(Source: WIPO)

Hence, Nigeria will be a force to reckon with in dictating the pace of development in the next material era if the commitment to fund research and innovation is reasserted. A strong policy is required to direct research activities and identify National priorities. Sustained commitment to reward innovations especially those that result in significant economic prosperity should be incorporated into such policy.

5.0 Researching for Sustainable Development

The term sustainable development was, brought to limelight by the World Commission on Environment and Development popularly referred to as the Brundtland Commission in 1987.

The Brundtland report defined Sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs".*

Sustainable Development Goals (SDGs) concept originated from the UN Conference on Sustainable Development, Rio+20; in 2012 to create universal goals which take into account the 3 pillars of Sustainable Development - Economic, Social and Environment.

Material Research and innovation focus sustainable utilisation of natural resources for production of goods and services in such a manner that zero – landfill is attained through reuse and recycling. This prolongs the life span of fresh materials in circulation and extends time frame before fresh raw materials are required. Recycling and generation of wealth from waste is becoming popular, hence the activities of material scavengers is a common sight and all members of the populace are developing the habit of not 'filling' the land but converting it into cash or kind through outright sales or exchange for other materials. The frequent sight of long haul vehicles on our road with scraps for remelting at various facilities attests to the fact that resources conservation is becoming a culture.

Point must be made here that mere remelting scraps without proper sorting and certain degree of refining as practised by private steel companies in Nigeria will lead to continuous degradation of steel product with each level of recycling. This is not a good recycling and reuse practice.

Biodegradable plastics: One of the notorious environmental pollutants is the plastics. The situation is made worse by non-degradable nature of plastics. Shifting to biodegradable plastic will create a more environmentally healthy atmosphere considering the volume of plastic waste generated annually worldwide.

Plastic waste recycling: Polythene bags are presently been made from recycled materials. When next you get a polythene bag from supermarket, take time to note how many times the poly has made the rounds. Plastic wastes have found their ways to solve the road construction problem in swampy environment.

High strength steel: Steel is renowned for being 100% recyclable. The decline in consumption and production is partly due to a shift from quantity to the quality of production. Innovation has helped in increasing the strength of steel many folds thus reducing the quantity required to satisfy the various need. Innovation has produced such steel with massive strength that could be produced into cables to arrest aircraft landing on Aircraft carrier.

Nanomaterials: Going nano will substantially reduce the pressure on the natural endowment. The quantity of natural resources required to produce materials of amazing strength and properties is so insignificant.

Secondary metal in circulation: Metal smelting and refining are energy consuming process. The quantum of energy requirement reduced drastically when scraps rather than ore are used. Innovative ways are thus emerging daily to bridge the gap between primary and secondary metals in terms of quality.

Sustainable Development Goals (SDGs) is global developmental agenda that evolved from the preceding Millennium Development Goals (MDGs). One of the weaknesses in the planning and execution of MDGs is the low consideration for Engineering. The anomaly in MDGs has been corrected in the formulation of the Sustainable Development Goals (SDGs) which identified the involvement of Engineering and Technology as being crucial to attainment of the SDGs by 2030. Of the 17 goals, Goals 6 - Clean Water and Sanitation, Goal 7 - Affordable and Clean Energy and Goal 9 - Industry, Innovation and Infrastructure respectively requires large Engineering involvement and has considerable overlapping effect with other goals. Material Innovation is expected to play a vital role in the attainment of this goal. The noble effort of the Nanotechnology research unit of Federal University of Technology, Minna as related to the 3 goals are as follows:

Carbon Nanotubes, Nanoclays, Nanosilvers and Magnetite nanoparticles are being investigated for use in the treatment of wastewater in the first instance and possibly portable water in not too distant future. A portable and multipurpose filter is a product expected from this effort.

A section of the unit is working assiduously on clean energy by using nanoparticles in various ways to develop more efficient solar cells. This is in addition to the breakthrough by the leader of the group in fuel cell technology.

Huge resources are expended annually on protection of pipelines for transportation of crude oil, refine product and water from corrosion. Procedure for CNT coating on mild steel was successfully developed and other nanoparticles are being investigated for use in corrosion protection.

Figure 4: Three of the SDG Goals that requires significant Engineering Input

6.0 My Reflection on the State of Iron and Steel Industry in Nigeria

6.1 Background Information

The Nigerian dream of establishing a viable steel industry was captured in the third National Development plan (1975 – 1980). Based on the feasibility study and the survey of raw materials carried out by Russian experts, a recommendation of time-tested and traditional route of steel making based on combination of Blast Furnace for pig iron and Basic Oxygen Converter for steel production was adopted. Also contract to actualise this lofty dream was awarded to Russian firm - Tiajprom Export (TPE) through various agreements between 1976 - 1978 thus giving birth to Ajaokuta Steel Complex (ASC) – an integrated steel making plant.

At about the same time, another contract culminating in the establishment of Delta Steel Company (DSC) was signed with a German-Austrian consortium to install a turn-key Electric Arc Furnace (EAF) with direct reduced iron (DRI) technology in Ovwian-Aladja, Delta State with completion date scheduled for 1981. Alongside DSC, contracts were awarded for three Inland Rolling Mills as follows: Jos Steel Rolling Company and Oshogbo Steel Rolling Company were awarded to German companies while Kastina Steel Rolling Company was given to a Japanese firm. These ambitious projects were expected to produce 2.3 million tons of steel as reflected in Table 8.

Table 8: Capacity of Public Steel Company as Awarded in 1970s

S/N	Company	Capacity (tons)	Remarks
1.	Ajaokuta Steel Company (ASC)	1.3 million	Structural product. 2nd phase - 2.6 million tons with flat product line. 3rd phase is 5.2 million tons.
2.	Delta Steel Company (DSC)	1.0 million	To roll 330,000 tons in-house while supplying 220,000 tons to each of the Rolling Mills.
3.	Jos Steel Rolling Company	220,000	To receive supply from ASC
4.	Oshogbo Steel Rolling Company	220,000	To receive supply from ASC
5.	Katsina Steel Rolling Company	220,000	To receive supply from ASC

While the three rolling mills and DSC were completed on schedule, ASC remained an on-going project after over 40 years of intermittent construction work.

DSC became operational 29 January 1982 and equipped with 1.5 mtpa pellet plant, two Midrex DRI plant of 510,000 tpa capacity each, 1.8 mtpa electric arc furnace with three, 6 strand continuous casting plants and 320,000 tpa 18-stand rolling mills and a power plant of 110 MW. DSC was strategically located close to oil fields in the Niger Delta for the supply of gas for direct reduction of iron. Ajaokuta is an integrated Steel Complex and has the facilities presented in Table 9:

Table 9: Facilities at Ajaokuta Steel Complex

S/N	Type	Plant Unit	Capacity (p.a)
1	Iron and Steel mills	Blast furnace	
		Sintering Plant	
		Raw Materials Preparation and Handling System	2,640,000 tonnes
		Alumino-silicate Refractory Plant	43,400 tonnes
		Tar-bonded Dolomite Refractory Plant	8,800 tonnes
		Lime Plant	91,000 tonnes
		Coke Oven Battery	440,000 tonnes
		Oxygen Plant	36,000 m^3/hr
2	Rolling Mills	Light Section Mill	400,000 tonnes
		Wire rod mill	130,000 tonnes
		Billet Mill Section	795,000 tonnes
		Medium Section and Structural Mill	560,000 tonnes
3.	Engineering Works Complex	Foundry and Pattern Making Shop	7,000 tonnes
		Forge and Fabrication Shop	8,800 tonnes
		Machine and Tools Shops	19,000 tonnes
		Power Equipment Repair Shop	Repair of electric motors and generators
		Rubberizing Shop	Repair of Conveyor belt, manufacturing of seals etc
		Erection Base	Fabrication and assembly of various structures and components
4.	Power Plant	Thermal	110 MW

6.2 Reflection on ASC and DSC

The DSC contract awarded in 1975 was commissioned in 1981 while ASC that commenced at about the same time remained uncompleted 40 years after. What are the factors responsible for the delay in completion?

The following are the factors:

(1) ASC is a metallurgical complex and larger in size and scope than DSC. The approach of the two companies to

steel making also differ with ASC requiring more ancillary facilities than DSC.

(2) The Contractors and the nature of contract also differs: DSC was handled as a turn-key project by an Austro-German firm, a capitalist firm from Europe. The main facilities of ASC was handled by Tiajexprom - a government-owned outfit from a Socialist state.

(3) The Contractor that built DSC was able to secure a loan to complete the Project on behalf of and to be repaid by the Federal Government of Nigeria. Thus, the funding and administration of the fund had little or no interference from the Bureaucracy of the Nigerian government. Tiajexprom on the other hand comes from a Socialist setting and could not arrange for financing the project. Dealing with a Capitalist economy and a corrupt one at that became a nightmare for the company, it was thus not surprising that the ancillary facilities being handled by companies from Capitalist economy were better funded and got to reasonable level of completion while the main contract dragged on till date on the excuse of lack of fund.

6.3 My Suggestions

While the discussion rages on the appropriateness of the two divergent approaches to steel making by ASC and DSC, the tales of 4 steel mills as told by P. C. Okonji is quite revealing. A plant similar to Ajaokuta was built about the same time in India (Visag Steel Plant) and the production capacity rose to 6.3 million tonnes per annum. Another plant of same make and capacity as DSC built by Saudi Arabia – Haeedd won the contract for the supply of steel to Brazil to execute huge construction embarked upon by the country preparatory to FIFA World Cup – Brazil 2014.

The deduction from this is - blame not the technology, rather, blame Nigerians and their unconventional approach to Steel

Development.

(1) The major problem hampering the completion of ASC is corruption. If the monster is not tamed, another 300 or 513 million USD investment as being proposed by various stakeholders will not make any difference. ASC holds the record of being the most expensive on-going steel works worldwide while DSC held an unenviable record of being the most flamboyant steel plant whose CEO used private jet as official transportation means.

(2) The problem of circumventing due process in the privatization or concession of the Steel plants has cost the nation a fortune. The nation may remain at the mercy of the major beneficiary of the hurriedly packaged concession, deliberately screwed against the national interest. Future process should follow due process and be transparent.

(3) There is need for a review of the privatization of DSC to the Stallion group to ensure that the Group has what it takes to run the plant in terms of technical capability and financial muscle. A situation where the so-called Direct Foreign Investment was fraudulently transformed to license to use DSC asset to collect loan from Nigerian Banks should never be allowed to happen again. It is doubtful if DSC can survive another botched privatization exercise.

(4) A reputable Steel Producing Firm selected in a transparent bid should be granted concession to run the completed segment of ASC on commercial basis with emphasis on the Medium Section Mill. The mill is capable of producing rails which will be required in abundance if the government pronouncement on accelerated rail development will be backed up by action.

(5) Government intervention at every stage of a coordinated privatisation or concession process should be limited to providing infrastructural support - rail linkages, gas supply, dredging, etc.

(6) The completing the Blast Furnace/BOF will require

Government direct intervention. This intervention should be less of GRANT and more of **Financial Guarantee** for the private concern (that would have proven themselves at the previous stages) to access international funding to complete the project.

(7) The factor of indigenes should be carefully considered at every stage.

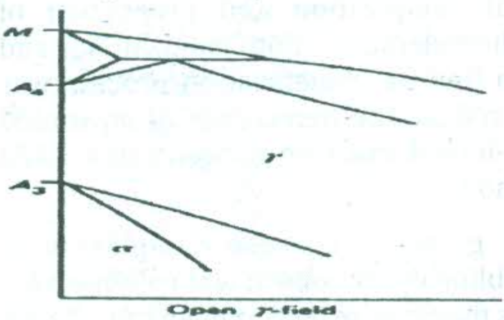
Finally, to tackle steel sector problem is a herculean task and will required long term commitment of resources and the political will from the Government of the day to follow through.

6.0 My Contributions

My research activities focus on the steel industry. We explored ways of adding value to mineral deposits from which vital elements to steel making process could be obtained. We characterized and beneficiated Manganese and Chromium ores from various locations in Nigeria. We also ventured into development of new Engineering materials such as Metal and Polymer Matrix Composites. We are presently working with the Nanotechnology Unit of CGEB to explore nanocoating for corrosion protection and nanoclay for water purification.

6.1 Manganese Ore for Ferro-manganese

Manganese is used in steel making as an alloying element to modify strength, toughness and hardness and to also serve as deoxidizer and desulphuriser. It acts as 'austenite-stabilizer' by lowering the temperature at which austenite transforms to



Mangenese as Desulphuriser:
$(CaO) + [S] + [Mn] = (CaS) + (MnO)$

Mangenese as Deoxidiser:
$[Mn] + [O] = MnO$
$[Fe] + [O] = FeO$

Fig. 13: Manganese as a Austenite Stabiliser

Majority of steel making countries apply manganese into steel in Ferro-manganese form. Solid minerals development in Nigeria is one of the strategic approaches towards steering the economy away from 'monoeconomy'. If Solid Mineral Development policy is well conceived and appropriately timed, it could be the nation's bail-out from the current recession. About 80% of industrial raw materials are imported because of the inability of the country to add value to abundant mineral resources to the level of application in the relevant industry.

The motivation for our interest in Manganese lies in the quantum of ferro-manganese that will be required to feed Nigeria Steel Industry and the huge burden this will impose on foreign currency demand and profitability/competitiveness of our Steel Industries. Abundance of Manganese ore is located at various parts of Kaduna, Kebbi and Niger State. The Ka'oje Manganese deposit was one area of our research interest. We explored the possibility of producting of high manganese mineral concentrate from Ka'oje terrestrial manganese ore for Ferro-manganese production as a way of improving the local content in the nation's steel industry.

The mineralogy study of the ores was carried out as a troubleshooting tool for both ore analysis and processing. Microstructure analysis was used to determine the mineral distribution, grain sizes, liberation sizes and minerals locking characteristics of the ores. Characterization of the ore was done to establish the chemical composition and proportion of constituent minerals and their elements (both major, minor and trace elements) present in the ore. Beneficiation process was carried out on the ore to reduce the percentage of unwanted minerals and turn the as-mined ore into concentrates using Gravity Concentration method.

The Ka'oje metallurgical grade manganese samples were subjected to Jigging and Tabling operations in wet condition for value addition. Ferruginous manganese ore samples from Ka'oje were successfully upgraded to metallurgical manganese concentrates which could be used as feed in ferromanganese production. Metallurgical manganese ore samples were also further enriched to higher Metallurgical grades during wet gravity separation techniques. X-Ray diffraction analysis of the as-mined ore samples affirmed the presence of pyrolusite as the major manganese mineral in the ore; existing alongside with iron mineral present as hematite optically identified by transmitted infrared light microscopy. The ED-XRFS results showing the critical constituents are presented in Table 10.

Table 10: ED-XRF Results of the Analysis of Ka'oje Manganese Ore

Sample	% Al_2O_3	% SiO_2	% P_2O_5	% CaO	% TiO_2	% MnO_2	% Fe_2O_3
'A'	16.01	21.60	0.31	1.49	1.16	31.01	19.07
'B'	13.58	10.65	0.30	2.05	0.74	54.96	11.06

One crucial deduction from Table 10 is that a simple beneficiation process of sorting could add enormous value to Ka'oje ore if sample 'B' could be isolated for treatment. The Jigging and Tabling tests successfully upgraded the Ka'oje metallurgical ore to feeds usable in ferro-manganese production. Jigging test concentrates assayed 51.54% MnO minimum recovery level with an enrichment ratio (ER) of 1.02; while concentrates from Tabling operation assayed 91.11% MnO maximum recovery with 1.14 ER value.

It is noteworthy that in the first quarter of 2014, manganese (Mn) concentrate with 52% Mn cost $328.11per metric ton while the same Mn ore having 33-36% Mn cost only $148-162.

The Madaka (Niger State) Manganese deposit was also investigated for the production of Battery-grade Chemical Manganese Dioxide (CMD). Pulse test of the battery, using Coulumb-counting method showed the ability of the produced CMD to maintain long storage life, making it a desirable material in production of various MnO_2-based batteries.

Table 11: Result of Gravity Concentration of Ka'oje Manganese Deposit

S/N	Sieve Size	Assay Feed		Assay of Concentrate		Recovery	ER
		MnO	SiO_2	MnO	SiO_2		
'A'	-780+500	36.83	28.30	40.35	22.20	94.59	1.10
	500+355	36.83	28.30	38.29	24.17	89.00	1.04
	-355+250	36.83	28.30	37.02	25.80	88.13	1.01
	-250+192	36.83	28.30	42.88	25.38	83.62	1.16
	-192	36.83	28.30	42.96	25.10	75.05	1.17
'B'	-780+500	54.96	10.65	58.46	5.90	89.52	1.06
	500+355	54.96	10.65	58.53	5.88	86.57	1.06
	-355+250	54.96	10.65	59.77	4.92	84.72	1.09
	-250+192	54.96	10.65	59.12	3.95	81.88	1.08
	-192	54.96	10.65	60.30	4.01	77.26	1.10

In our work on Manganese, we successfully raised the manganese content of Ka'oje ore beyond 50% mark thus setting stage for production of ferro-manganese from the deposit. Madaka was established a viable raw material forMnO_2-based batteries.

6.2 Anka Chromite Ore

Chromium is largely used as alloying elements in steels for the production of stainless steels. It increases the hardness, strength, yield point, elasticity and resistance to corrosion, heat and acid. Therefore, chromium is essentially used for the production of all varieties of stainless steels. Chromium steels are also used for the manufacture of heat and acid resistant steels, structural tools, ball and roller bearings steel. Chromium is added in form of ferro-chromium. While the global production of Chromite ore stands at 25 million tonnes, Ferrochrome production is around 7 million tons. Nigeria is presently not making any contribution to this global output in spite of chromite deposits in Zamfara, Sokoto and Katsina States.

Chromite ore ($FeOCr_2O_3$) is the most important mineral occurrence of chromium, and the deposits located at Anka Local Government Area of Zamfara State formed the focus of our work. It involves the analysis of collected ore samples from Anka in Zamfara State. The samples assaying 36.84% of Cr_2O_3 was subjected to beneficiation process in order to enrich the ore, in terms of the Cr_2O_3, using magnetic separation. The results obtained after the analysis of the beneficiated ore using wet chemical analysis and Atomic Absorption Spectrometer show that Cr_2O_3 content increased to 48% with a maximum Cr:Fe ratio of 6.2:1. The content of Cr_2O_3 is high enough and can be used for ferro-chromium alloy production.

The characterized ore was successfully upgraded to meet specification for metallurgical use by conventional ore dressing methods. It was also established that chromium ore can best be beneficiated for maximum chromium recovery in fraction ranges berween 100 – 200 mesh (BSS).

The global standardisation established that Ferro Chrome, with even 50% chromium content, can be efficiently used in the production of stainless steels and other special alloy steels. The Anka Chromite ore at 48% is therefore adequately suitable for production of ferro-chrome.

Table 12: Compositional Analysis of Raw Sample of Anka Chromite Ore and Beneficiated Sample

Molecules	FeO	MgO	Cr2O3	Al2O3	SiO2	CaO	Others
Composition % - As-mined	21.51	14.00	36.84	11.00	13.74	2.24	0.67
AAS Analysis	13.80	10.00	44.68	16.76	2.46	1.34	10.96
Wet Analysis	11.57	11.35	43.97	16.38	3.56	2.21	10.96

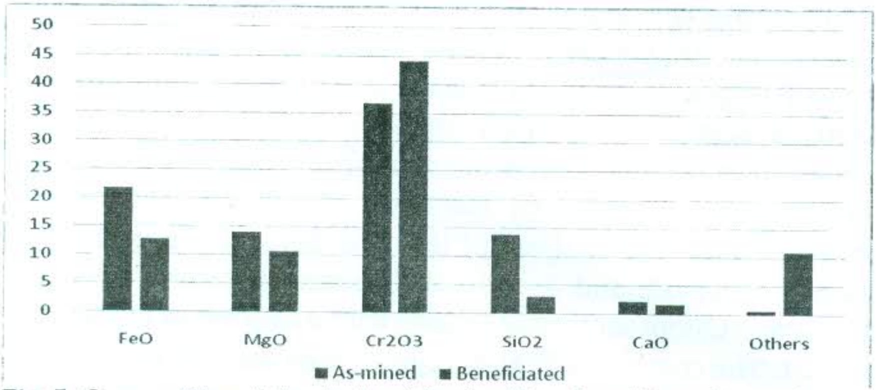


Fig. 5: Compositional Analysis of the As-Mined and Beneficiated Chromite Ore

6.3 Material Development

6.3.1 Metal Matrix Composites (MMC)

Composites are relatively new engineering materials in which reinforcement materials are incorporated into the metal matrix to improve its properties. Our work was the first serious attempt that developed MMC of Particulate brand in Nigeria. The work focused Aluminum alloy matrix with three different reinforcement materials namely Alumina, Silica and Mill Scale. Various equipment and tools were successfully designed and fabricated for the purpose of synthesizing Metal Matrix Particulate Composites (MMPC) by stir casting technique. Series of trial experiments were carried out and the optimum processing parameters were established. Such include 4-Blade impeller stirrer, 1000rpm stirring speed, stirring temperature of 740–760^{0}C range and variable stirring height. The strongest among the successfully developed Al-Si/Al_2O_3 composite was the one reinforced with 5 wt.% particles having the Ultimate Tensile Strength (UTS) and yield strength values of 180.85MPa and 150.28MPa, respectively. The produced composites were very brittle with percentage elongation close to zero. Al-Si/SiO_2 composites were developed with silica of two different grain sizes. The highest strength of 193.58MPa was recorded in the composite loaded with 3 wt.% fine silica particles (SiO_{2f}). The coarse silica (SiO_{2c}) loaded composites were inferior to fine silica reinforced equivalent with the highest UTS of 182.84MPa obtained for a 10wt.% loaded composite while in general, no appreciable ductility was observed in Al-Si/SiO_2. But Al-Si/SiO_2 composites are generally more ductile than the equivalent Al-Si/Al_2O_3 composites.

The introduction of mill scale obtained from steel rolling mills into Aluminum matrix is a new approach in composite production. No significant improvement in the strength was recorded for composites with less than 10wt.% reinforcement. The maximum UTS attained is 160.53 Mpa, which is barely an increase of 3% above the unreinforced specimen. Generally, there was adequate distribution of reinforcement throughout the matrix. The hardness for all composites improved considerably.

6.3.2 Polymer Matrix Composites (MMC)

Our work on Polymer Matrix Composites focussed on natural reinforcements such as oil palm (EFB) fiber, coconut fibre, wood particulates, palm kernel shell and others. The effect of the various surface treatments to enhance the wettability of the reinforcement by the matrix was studied and the properties of the Composite produced were also duly investigated.

Natural fibers are abundantly available and potentially valuable biomass that is under-exploited. Regardless of many advantages, one shortcoming of use of natural fiber is the deformation after being formed into composite structure which is caused essentially by poor adhesion at the interface with the polymer matrix. In this study, the effect of silane treatment on the impact strength properties of oil palm empty fruit bunch fiber - reinforced polyester composites was evaluated. The oil palm EFB fibers were used in two distinct tangled mass; 'as natural'-untreated and treated forms. Composites of EFB fiber wastes up to 60% by weight in polyester matrix were fabricated by hand lay-up technique and analyzed. As expected, the results show that the composites of oil palm EFB fiber treated with phenylsilane exhibited improved impact strength properties from 10% fiber content to 60% fiber content after which problems of poor wettability set in. The results permitted the comparison of the impact strength performance of the untreated and surface-treated oil palm EFB fiber composites. Oil palm EFB fiber represents a promising alternative to wood fillers and glass fiber in the production of composites for medium impact strength application in engineering.

The values of impact strength properties of oil palm EFB composites are outstanding and could further be improved with suitable fiber surface treatment. The surface treatment also imparted dimensional stability on the composite. The relatively high dispersion and variance with changing fiber content may be taken as a consequence of the intrinsic variability found on natural plant fibers that ranges from their non-uniform cross-section that often preclude property prediction in application.

The oil palm EFB fiber composites could serve as valid alternative to replace some conventional fiber systems as reinforcement in polyester matrix especially in areas of medium-to-low impact strength property requirement. Such applications include areas where gypsum board, wooden panels and ceilings are in present use. The fact that these oil palm EFB fiber composites are impervious to moisture and still support deformation, represent advantages in comparison with the relatively brittle gypsum board, which deteriorates in contact with water.

6.3.3 Wood Particle reinforced Polymer Matrix Composites

Wood particles from three species of wood namely - Akpontu, Madobia and Melina were used as reinforcement in polymer matrix. Compression moulding technique was used to incorporate the wood particles into low density polyethylene. To enhance the wettability of the reinforcing phase, surface treatment using sodium hydroxide was carried out on the reinforcement. The composite based on the soft woods (melina) possess better mechanical strengths than hard woods. The optimum reinforcing proportion for hard wood (madobia) is 40% which gave the best mechanical properties. The best mechanical properties for akpontu particles reinforced composites stand between 30 to 40 wt%. Therefore, 40% by weight of the hard wood particles is the overall equilibrium point for mechanical efficiency of the wood polymer composites compounded. The second major finding was that the deviation from the expected highest value of compressive and impact strength at 40 wt% wood particle reinforcement could be as a result of the non-uniform particle distribution in the matrix as alluded to by the SEM images.

The result suggests that water absorption rate of WPCs is high in the first few hours and can reach saturation point during which water uptake stops almost permanently. 50 wt% AKP absorbed the slowest in the first 100 hours while 30 wt% AKP completely stops absorbing water after the first 100 hours. However, 40 wt% AKP has the highest overall water absorption.

For the hard wood, however, 40% was found to be the best composition for wood particle reinforcement. Increasing particle load of madobia improved the strength and stiffness of the composites but decreased the energy required to break. It was also found out that water uptake increased with increasing filler content in agreement with earlier research reports. The result however suggested that water absorption rate of WPC was high in the first few hours. 50 wt% for akpontu absorbed the slowest in the first 96 hours while 30 wt% completely stopped absorbing water after reaching its saturation point in the first 96 hours. 40 wt% of wood reinforcement has the highest overall water absorption. Scanning electron microscopy (SEM), was used to study the interfacial interactions between the components of the composites.

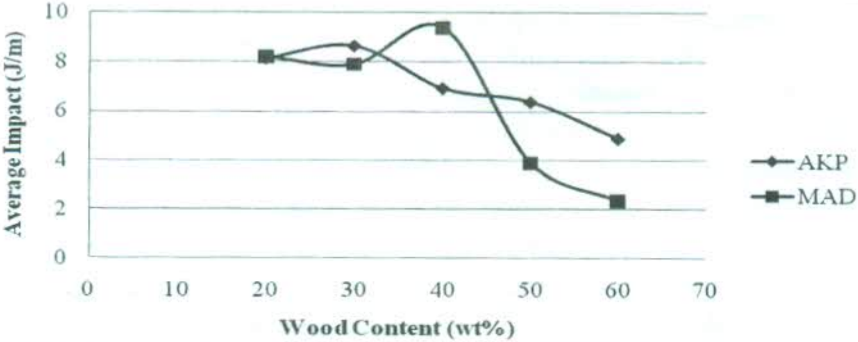


Fig. 6: Variation of Impact with Wood reinforcement

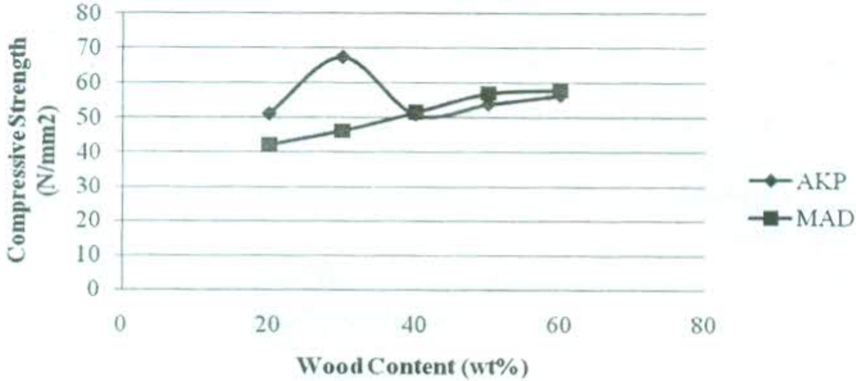


Fig. 7: Variation of Compression with Wood reinforcement

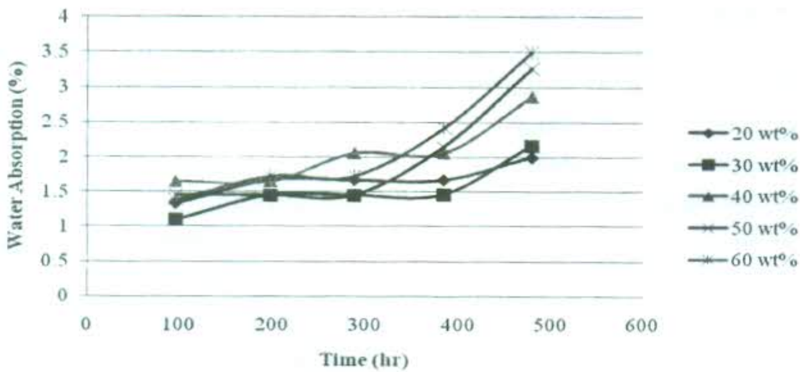
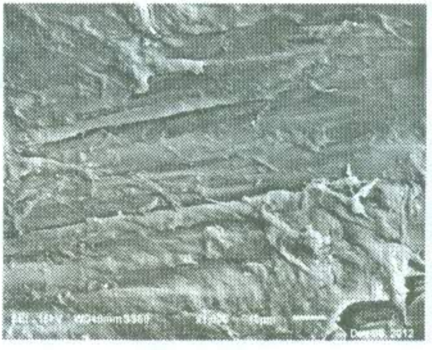


Fig. 8: Absorption – Time Curve for Madobia Particle Reinforced LDPE

The sample with 30 wt% particle reinforcement represents the most stable sample in water as its water absorption does not increase beyond the set 96 hours. This means that it will last longer than the other samples in use in a humid environment. The closest to it will be 30 wt%MAD followed by 20 wt%MAD with the lowest gradients. The sample with particle content of 40 wt% absorbed the same quantity of water in the first half of the period of 480 hours, but has the steepest gradient in the second half, which is an indication of uniform water absorption rate.



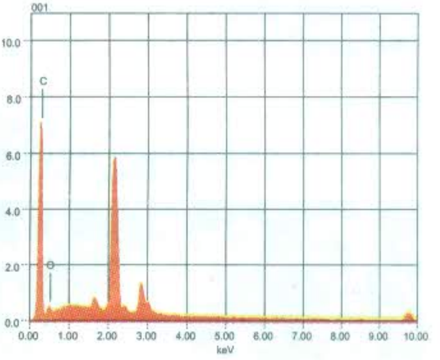


Fig. 12: SEM/EDS Microstructure for 30 wt%MAD in LDPE

6.4 Mechanical and Corrosion properties Enhancement using CNTs Coating on Mild Steel

Mild steels are used by machinists and fabricators for easy production of engineering components such as gears, cams, shafts, keys and hand tools. They are however known to be relatively soft and weak but ductile and tough. Many surface treatment methods have been developed and applied to enhance the surface properties of components produced from mild steel. Our work investigated the effect of carbon nanotubes (CNT) coating on the mechanical and corrosion resistance properties of mild steel. CNTs was produced by CVD methods and purified to remove the impurities. The Multiwalled Carbon nanotubes (CNTs) produced was used to coat mild steel samples at 900^{0}C and 950^{0}C for 30, 60 and 90mins. SEM image (Plate 1) of the sample revealed the presence of CNTs evenly spread on the sample surface. The mechanical properties test showed increase in the tensile strength, yield strength and micro hardness with increasing temperature and holding time, while the impact strength, percentage reduction in area and percentage elongation showed slight decrease with temperature and soaking time. The results of electrochemical polarization corrosion test revealed that the corrosion current and corrosion rate decrease with increase in temperature and holding time. On the other hand, the polarization resistant and coating corrosion efficiency showed increase in temperature and soaking time. These can all be attributed to the CNTs coating on the surface of the samples in addition to the dissociation and diffusion of the carbon atoms from the CNTs into the surface and sub-surface of the samples which increase with temperature and holding time.

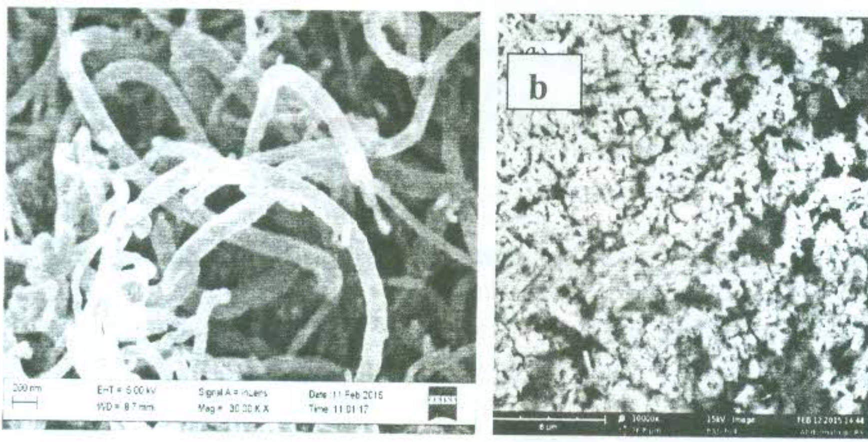


Plate: SEM micrograph of (a) As-produced CNTs and (b) CNTs coated Mild Steel sample treated at 900^{0}C for 30mins

7.0 Recommendations

'My Country is rich in minerals and gem that lies beneath its soil, but I have always known that its greatest wealth is its people, finer and truer than the purest diamond' – Nelson Mandela.

(1) The much talked about potential of Nigeria in terms of

natural endowment is becoming an old tune. The past belonged to minds creative and innovative enough to develop epoch materials and the only way to be relevant in the future is to emphasize more on human capital endowment and innovativeness in material engineering research.

(2) The National Science, Technology and Innovation Policy needed to be fine-tuned in line with the current reality. The commitment of the government to appropriate 1% of the GDP should be followed through while the government priority for research and innovation should be clearly spelt out.

(3) The current effort by TETFund to incentivise quality publication is good, the effort should however be directed towards stimulating innovation with special emphasis on patents and inventions with significant economic benefits to the Nation.

(4) Nigeria must make conscious effort to cover the ground lost in Steel and Silicon ages and the Nation should key in to research in new materials that are likely to give nomenclature to the future. Engineering Materials Development Institute in Akure should be further strengthened to deliver on this and other mandates.

(5) Government of the day should make the best use of the $400 million remaining from the $1bn loan obtained from Chinese for constructing modern gauge and double line rail network across the nation. Such step will create huge demand for rails and this could be a sufficient incentive and a good market to activate the medium section mill at ASC and could further be used to encourage the production of liquid steel.

(6) More than 8 items of the 41 restricted items by CBN are direct or downstream product of steel industries. The restriction should be sustained to create the right atmosphere for prospective investors in the nation's steel sector.

8.0 Acknowledgements

Indeed my Solat, my sacrifice, my life and my death is dedicated to Allah, the Lord of the Universe. To Him alone goes my thanks for the gift of life, good health and true guidance. I thank Him for piloting my life from the stage of non-existence, through childhood struggle with diseases and ill-health, through the long sojourn in hostile weather condition to this glorious moment. All along, it has been little of my personal effort but abundance of His Mercy and Grace.

I still thank Allah for His choice of parent for me. My Father – Late Alhaji Hameed Olanrewaju Amoo Abubakre was a role model, a friend, a mentor, and a confidant – all rolled into one. My Mother – Alhaja Rofiat Ahinke Abubakre – lived a life of continuous struggle. I witnessed the many life-threatening battles she fought and the enormous hardships she endured just to see us to this stage in life. I remain ever grateful and my fervent prayer to Allah is to have mercy on you both far more than you cherished me in my childhood. I am grateful to my 'Second Mother' (Step-Mother) – Mrs. Hajarat Abike Abubakre for her care and prayers that has strengthened me in no small measures.

Thanks to Banji Tajudeen Abubakre for being there always. Recollect the JAMB letter with which you woke me up from the Bora Hostel of Institute of Animal Health and Husbandry (IARTH). The race against time for travel documents with impossible time line. May God reward you abundantly and preserve us for each other. To my other Siblings - Risqat, Nurat, Faoziyah, Tawakalitu, Abdus Sami'u – I thank you for your contributions that get us here. Alhaji and Alhaja Adefajo, Mr. and Mrs. Bakare, the Omotoshos, the Salahudeens and all our In-laws – you are all acknowledge for various crucial roles you played in my life.

My spiritual mentor is Alhaji Yusuf Shittu at Ife – Baba Oluorogbo. He not only laid strong foundation for my Islamic education but

contributed significantly in complimenting the moral upbringing by my Parents. My subsequent spiritual guides up till the present – Sheikh Abdul Wahab Solahudeen, Imaam Bashir Ahmad Yankuso are duly acknowledged. Jazakum Lllahukhaeran to you all.

My Teachers – Ustaz Abdul Hameed, Late Alhaji Mustapha Adedeji, Prince Bisi Adesigbin at primary school level. Engr. Remi Adebayo, Alhaji Adiatullah, Mr. Alabi, Mrs. Ajakaye at secondary school level. Professor Klimenko, Drs. Kashaev, Anishenko, Solod at the tertiary level. They collectively fed me from their wisdom and fountain of knowledge.

I acknowledge with thanks my PhD supervisor – Prof. R. H. Khan. Thank you for giving me hope and successfully seeing me through my PhD at a time when getting a PhD in Nigeria is synonymous to squeezing water out of the rock. Seeing your product present inaugural lecture is a rare privilege. We thank God for your productive life and pray for good health and more productive years ahead. The Father figure to Mechanical Engineering – Prof. F. O. Akinbode is appreciated for building a strong and united department that was envied by many. My current HODs – Dr. A. O. Olugboji and Dr. A.S. Abdulrahman are appreciated for strengthening the building bricks solidly put in place by the founding fathers of the department. The entire members of Mechanical Engineering family and by extension Materials and Metallurgical Engineering are appreciated for creating enabling environment for achieving this pinnacle.

I thank previous administrations for various reasons: Prof. Sulaiman O. Adeyemi for giving me job in spite of missing my schedule for interview. Prof. Hamman Tukur Sa'ad for entrusting me with administrative responsibility. Prof. M. S. Audu for pronouncing me a Professor having earlier concluded the process of my elevation to Associate Professor that got stalked along the way. He equally challenged me with the management of Step-B project and acceded to nearly all my request to successfully pilot the project. The current Vice-Chancellor – Prof. M. A. Akanji is appreciated for the motivation and full support for this inaugural lecture. He came in at a crucial moment of winding down Step-B. His unflinching support, his belief in my judgement and his approval of my decision to take certain risk at certain crucial moment is responsible for whatever success the Project attained in FUT, Minna. Thank you Sir.

My students are appreciated for their cooperation and making learning a living as a Chalk Peddler a worthwhile engagement. My Postgraduate students are commended for their contribution to our research effort. Nanotechnology Research Unit of Centre for Genetic Engineering and Biotechnology under the leadership of Dr. A. S. Abdulkareem is redefining research activities in this University and I am proud to be part of your success stories.

I thank all my friends and they are indeed numerous, starting from Prof Abdulkabir Raji, the Darus Salam group (Engrs. Baruwa, Bale, Aderibigbe, Kajogbola, Ayoola, Faniran and others). I enjoyed at some points very strong spiritual buoyancy from the IBF (Profs. Iyaka, Sanusi, Junaid, Drs. Salako, AbdulKareem, Azeez, Oke) The group gave birth to Al Halaal Cooperative Multipurpose Society. The IDG (Alh. Alatise, Engr. Sulaiman, Bro Animashaun) for providing enabling Da'wah platform at some stages.

I thank the CEFE Coordinator – Dr. Caroline Alenoghena and the entire CEFE Trainers in FUT, Minna. I must thank the immediate past Coordinator – Prof. Mrs. Z. D. Osunde not only for raising the stake of CEFE training from where we left it but for her effort as Chairperson of Seminar and Colloquium Committee. The bulk of this presentation was prepared during her tenure.

Prof. M. A. T. Suleiman is acknowledged for his role in the supervision of my first PhD candidate. Prof. A. O. Osunde for being a role model and for being instrumental to some of the challenging assignment I carried out for the University. Prof.

(Mrs.) S. N. Zubairu – was my Boss in PG School. Prof. Onifade, Prof. Muazu and Prof. Adediran (Unilorin) are appreciated for various reasons.

I recollect, with deep feeling of satisfaction, the challenge of STEP-B project and the collective effort by all the stakeholders to turn the fortune of the project around. The proponents led by Prof. S. A. Garba, former Project Managers - Profs. Dalhatu Muazu and G. D. Momoh and all the Project Officers are appreciated for making the project a "Success Story."

I thank the staff at the Dean's office, the Heads of Departments, the Standing Committee members and the entire SEET staff members for the trust and cooperation so far.

Finally, I thank Allah for the choice of wives for me. My deep appreciation goes to Alhaja Wasilat Bosede Abubakre. Thank you for your patience and endurance when life was tough. You tolerated my long absence from home and took adequate charge of the home front. The new addition to the family – Hafsat Bello for the love and care. You are and I pray you remain additional blessing to a blessed family.

My Children - biological and the foster are duly acknowledged. You have been such good and understanding children. My aspiration is to follow the footstep of my father and shower on you, my love, care and affection and spare nothing to bring you up as God conscious, hardworking, upright and successful individuals. So help me God.

To the audience – I thank you for your attention.

References

Abubakre O. K., Muriana R. and Nwokike P., "Characterization and Beneficiation of Anka Chromite Ore Using Magnetic Separation Process," *Journal of Minerals and Materials Characterization and Engineering*, Vol. 6 No. 2, 2007, pp. 143-150. doi: 10.4236/jmmce.2007.62012.

Abubakre O. K. (2007) "Correlation between Growth in Steel Industry and Development of African Nations" *Global Journal of Mechanical Engineering, Uniuyo,* Vol. 8 No. 1 pp. 22 – 28.

The Nation Newspaper, 26/7/2016

Allan Cottrell (1995) "An Introduction to Metallurgy." Edward Arnold (Publishers) Ltd.

Al Gore (2007) "The Assault on Reason" Bloomsbury Publishing, London.

Anyakora A.N., **Abubakre O. K.**, and Mudiare E. (2011) "Effect of Fibre loading and surface treatment on the flexural Strength of polyester matrix reinforced with oil palm frond fibre wastes" *Journal of Engineering and Pure and Applied Sciences* 7. 68 – 74.

Bangwei Z. and Yinjian Y. (2011) "On the Substance of Civilization in Human Society Entering into the Nanomaterials Age" *Arts and Social Sciences Journal,* Volume 2011: ASSJ-28. Pp. 1 – 12.

Bankole M. T., Mohammed I. A., Abdulkareem A. S., Afolabi A. S., Kariim I. and **Abubakre O. K.** (2015) "Nanotechnology Applications in National Defence: A review" *Proceedings of the 1st International Engineering Conference (IEC), F.U.T., Minna, Nigeria.*

Editor (2016) 'Apple buys a Nigerian-owned ICT firm for $1 billion' The Guardian. Monday 12 December 2016 http://guardian.ng/news/apple-buys-a-nigerian-owned-ict-firm-for-1-billion/

Elijah I. Ohimain (2013) "The Challenge of Domestic Iron and Steel Production in Nigeria." *Greener Journal of Business and Management Studies* Vol. 3 (5), pp. 231-240.

Enibe S. O. (2008) 'Engineering Systems Analysis and Optimization' 37th *Inaugural Lecture of the University of Nigeria delivered on August 26, 2008.*

Gonzalez-Fernadez Africa (2012) 'Nanotechnology for Medical Applications' 1st Pan-African Summer School in Nanomedicine, Pretoria, South Africa. 4th – 10th November, 2012

Helsen J. A. and Missirlis Y. (2010) *Biomaterials*, Biological and Medical Physics, Biomedical Engineering, DOI 10.1007/978-3-642-12532-4 9,_c Springer-Verlag Berlin Heidelberg

History of Monarchy - James II 1437 - 1460 http://www.royal.gov.uk/HistoryoftheMonarchy/Scottish%20Monarchs.retrieved on 24th September, 2015.

Holy Bible - New International Version (NIV) (1 Samuel 17:39)

Holy Qur'an (Yusuf Ali Translation)

Kempski, A. and Kosak S. (1977) "Hittite Metal Inventories" Tel Aviv: Tel Aviv, Vol 4.

Lloyd R. (1970) "Early metallurgy of the Persian Gulf: technology, trade, and the Bronze Age World" American school of prehistoric research monograph series; vol. 2. Brill Academic Publishers, Inc., Boston.

Mandela Nelson (1995) 'Long Walk to Freedom' Little, Brown and Company. New York. P. 638

Mayowa Afolabi, **Abubakre O. K.**, Lawal S. A. and Raji Abdulkabir (2015) "Experimental Investigation of Palm Kernel Shell and Cow Bone Reinforced Polymer Composites for Brake Pad Production." *International Journal of Chemistry and Materials Research,* 3(2): 27-40.

Medupin, R. O. and **Abubakre, O. K.** (2015) "Effect of Wood Fibre Characteristics on the Properties of Wood Polymer Composites." *Journal of Multidisciplinary Engineering Science and Technology (JMEST).* Vol. 2 Issue 1. 101-105.

Medupin, R. O., **Abubakre, O. K.**, Ukoba, K. O.; Imoisili, P. E. (2013) Mechanical Properties of Wood Waste Reinforced Polymer Matrix Composites. *American Chemical Science Journal* Oct. - Dec. 2013, Vol. 3 Issue 4, p507-513. 7p.

Muriana R. A., **Abubakre O. K.**, Mudiare E., Ndlovu S., Issa A. W. and Arogundade A. I. (2013) Beneficiation of Ka'oje (Nigeria)

Ferruginious Manganese Ore for Metallurgical Applications, *Journal of Engineering Research,* Volume 18 No. 2. 85-96.

Obikwelu D. O. N. (2014) 'Metallic Materials: Challenges in the 21st Century Nigeria and Didactic Lessons from The 18th Century Industrial Revolution' *An Inaugural Lecture of the University Of Nigeria, Delivered On 19th June, 2014.*

Okonji Emma (2016) "From Zuckerberg, a Boost for Nigerian Tech Startups" Thisday Newspaper. 04/09/2016.

Olorunmaye J. A. (2012) "Energy Conversion and Man" 106th *Inaugural Lecture of the University of Ilorin, Delivered On 12th May, 2012.*

Postgate, J. N. (1994) "Early Mesopotamia" London. Rutledge.

Spoerl S. Joseph (2000) 'A Brief History of Iron and Steel Production' http://www.anselm.edu/homepage/dbanach/h-carnegie-steel.htm

Stephen E. Ambrose (2001) 'Nothing Like It In the World' Simon and Schuster. New York: p. 382.

Stephen L. Sass (2011) "The Substance of Civilization: Materials and Human History from the Stone Age to the Age of Silicon" Arcade Publishing. New York. P.303.

Uche, N. (2012), Nigerian Intellectual Property: Overview of Developments and Practice. *NIALS Journal of Intellectual Property [NJIP],* (2012), pp. 101-116

Wertime, L and Muhly J. D. (1980) "The coming of the Age of Iron" New Haven: Yale University Press.

2012 - 2016 FGN Budgets"Budget Office of the Federation, Federal Ministry of Finance" Abuja.

My Citation

Oladiran Kamardeen was born in June, 1963 to Late Alhaji Hameed Olanrewaju Abubakre and Alhaja Rafatu Ahinke Abubakre. He had his early education at Ansarul - Islam Primary School, Sabo, Ile Ife and had his First School Leaving Certificate in 1974.

In 1982, he successfully completed his Secondary School education with credit in English and distinction in the rest subjects at Modakeke Islamic Grammar School in Osun State. He won the Bureau for External Aid Scholarship to pursue his M.Sc in Metallurgical Engineering at Donetsk Technical University, Donetsk, Ukraine.

In 1989, he earned his M.Sc degree with distinction in Mechanical Metallurgy and later earned his PhD in Material Engineering from Federal University of Technology, Minna in 2002.

He joined the services of Federal University of Technology, Minna in 1990 as Assistant Lecturer and rose through the ranks to become a Professor in 2010. He is a seasoned teacher, researcher and administrator with over 26 years experience in teaching, research and mentoring young researchers across 5 Nigerian Universities. He has successfully mentored more than 15 Master degrees and graduated 3 PhD holders and co-supervised 5 others. He has served as External Examiner for Undergraduate and Postgraduate programmes for several Universities including Unimaid, Mautech, ATBU, ABU, FUTA, OAU, KWASU, BUK and has served as Reviewer to several National and International Journals. He has published over 55 scholarly articles in reputable National and International Journals and has assessed Professors and Associate Professors for numerous Universities. He also served as Resource Person for NUC and COREN accreditation team to several Universities and served INEC as LGA Returning Officer in 2014 Bye Election in Niger State.

His research interest covers Development of New Engineering Materials from local raw materials; Development of Ferroalloys from locally sourced ores, Development of Metal Matrix and

Polymer Matrix Composites. Nanomaterial application in Energy and Water purification, Nanocoating and Nanocomposites. He has served at various times as Head of Department, Deputy Dean, School of Engineering and Engineering Technology and Deputy Dean, Postgraduate School. He is presently serving as the Dean of School of Engineering and Engineering Technology. He successfully managed a Multimillion Dollars World Bank Project (Step-B) culminating in the establishment of Centre of Excellence in Biotechnology and Genetic Engineering in Federal University of Technology, Minna.

He served the Nigerian Society of Engineers (NSE), Minna Branch in various capacities since 2000 and became the Branch Chairman in 2010. He served in the National Council of NSE from 2010 - 2012. He was the National Technical Secretary of Mining, Material and Metallurgical Division of NSE and Auditor to Nigerian Metallurgical Society at various times. He is an Internationally Certified Entrepreneurship (CEFE) Trainer, a Coach and a National Advisor to CEFE International. He is currently a member of the Governing Council of the Federal University of Technology, Minna representing the Senate.

At the end of his Secondary Education, alongside the prizes as the Senior Prefect of the School and the Best Graduating Student, he won the prize for the Best Behaved Student. During his sojourn in Donetsk, he won Lenin's Prize for Academic Excellence - 1984-1986; 1987-1989 (our own equivalent of VC's List. He won the Professional Union Prize for the best foreign student - 1985. He won the University (FUT, Minna) commendation for prudent management of SWEP fund in 2001. He received Merit Award by Nigerian Society of Engineers, Minna Branch for meritorious service in 2013 and 2015.

He served as Consultant to G12, EU, GOPA PIND (Partnership Initiative in Niger Delta) among others.

He is happily married to Alhaja Wasilat Bosede and Hafsat Bello and blessed with Children.