FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA

# NATURE TO NATURE: THE MIRAGE OF MATERIALS LONGEVITY

BY:
ENGR. PROF. ABDULRAHMAN ASIPITA SALAWU
B.Eng. (ABU), M.Eng. (ATBU), PhD (UTM, Malaysia), FNMS, FNSE
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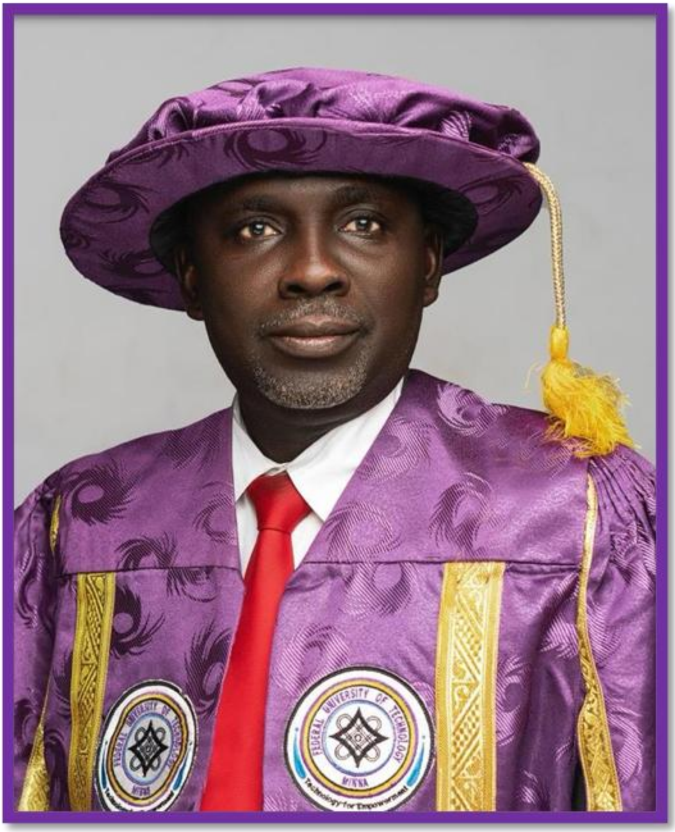
**THURSDAY 13TH AUGUST, 2026**



**Prof. Faruk Adamu Kuta**
B.Sc. (UDUS), M.Tech. (FUTMIN), PhD (ATBU)
**Vice-Chancellor**

**Engr. Prof. Abdulrahman Asipita Salawu**

*B.Eng. (ABU), M.Eng. (ATBU), PhD (UTM, Malaysia), FNMS, FNSE*

**Professor of Materials and Metallurgical Engineering**

# DEDICATION

**To my mother, Hajia Fatima Momoh Oshieza**

## APHORISM

Nature has a way of striking a balance in everything on earth as designed by God. Right from the creation of man to the present age, nature has always taken the lead, complementing the work of man, which aligns with its precepts. In contrast to humans or human-made objects, nature is the phenomenon of the physical universe, including plants, animals, landscapes, and other aspects and products of the Earth.

From time immemorial, as found in the Holy Books, God instructed man to be fruitful, multiply and subdue the earth (Gen. 1:28), and has made what is in the heaven and earth subservient to humans (Surat Luqman: [31:20], Surat Al-Nahl: [16:12]). This is a commandment that Engineers have consistently integrated into their work and daily life. Engineers by nature are professionals who invent, design, analyse, build and test machines, complex systems, structures, gadgets and materials to fulfil functional objectives and requirements while considering the limitations imposed by practicality, regulation, safety and cost. In an attempt to make life comfortable for the inhabitants of the planets, thereby participating in the work of creation, engineers have consistently explored natural resources and created state-of-the-art inventions while making conscious efforts to preserve the nature of the explored resources. Materials and Metallurgical Engineers are usually at the forefront of these explorations and the conservation of the available resources. Engineers specialising in materials and metallurgy by nature work with metals, ceramics, and polymers to develop products that benefit humanity and the planet. They are responsible for the development, processing, and testing of materials employed to create a vast range of products.

## EXORDIUM

Mr Vice-Chancellor, Sir, and the distinguished audience permit me to begin with the praises of Allah, the Almighty and All-knowing. O Allah, I ask You by Your mercy, which "embraces all things", and by Your strength, through which You dominate all things, and towards all things are humble and before which all things are lowered; And by Your invincibility through which You overwhelm all things, and by Your might, which nothing can resist; And by Your tremendousness, which has filled all things; by Your force, which towers over all things; And Your face, which subsists after the annihilation of all things; And by Your name, which have filled the foundations of all things; And Your knowledge, which encompasses all things; And by Your light through which all things are illuminated. O Allah, bless this august assembly (Amen).

I am humbled, honoured and privileged to pay the debt I owed the University Community as a Professor of this great citadel of Learning, the University of First Choice in Nigeria today.

Inaugural Lectures provide newly appointed professors with the opportunity to inform colleagues, the campus community and the general public (town and gown) of their work to date, including current research and plans, which is a time-honoured tradition adopted from Western Universities. I am confident that at the end of this lecture, your life will surely not be the same and that you will be fulfilled and the exercise will be worthwhile.

## 1.0 INTRODUCTION

"Rabbi shra li sadri wa yassir li amri" (My Lord, expand my chest and make my task easy for me)

Initially, human existence is supported by plants, water, soil, and rocks, which are the primary components of the Earth's crust. These components are abundant and useful for the sustenance of man and animals. Among these components are soil and rocks that are naturally formed with aggregates of minerals or mineral-like substances. The uppermost unconsolidated layer of the earth's surface includes essential and disintegrated components of mineral particles from rocks, water, humus or organic matter, and air, and is called soil. The rocks can be made up of one type of mineral, several minerals, or no minerals at all.

Minerals are naturally occurring inorganic solids that form through natural geological processes. Minerals are non-living and have a crystalline structure, meaning the atoms that make up the mineral are arranged in an orderly, three-dimensional pattern that repeats itself. Minerals are said to have a definite composition that is made up of specific proportions of certain elements. There are over 4,500 different minerals identified on Earth. Each has a unique combination of crystalline structure and chemical composition. These minerals require processing to make them useful for engineering applications, including iron ores.

Who are engineers?

Engineers are to add more value to the existing main components found on the earth's crust by designing or building machines, engines, electrical equipment, or things such as roads, railways, or bridges, using scientific principles. This brings about the development of different materials, including metals, alloys, composites, and nanomaterials.

The domain of Materials Science is the combination of physics, chemistry, and the relationship between the properties of a material and its microstructure. The development of this science allowed for designing materials and provided a knowledge base for engineering applications (Materials Engineering). For example, material and metallurgical engineers process natural minerals and materials and develop them by applying mathematics and scientific theories for structural support and aesthetics.

Mr Vice Chancellor, Sir, there is no doubt that nature is controlled by the Great Creator (God or Allah). Allah created everything in this universe, from humans (Man) to animals, plants, soils, rocks, air, water, etc. And everything created in nature will surely return to its state (Nature) after it benefits man and other living organisms (Brevik *et al.,* 2020). As mentioned in the following verse (Ayah 55) in the Holy Quran in Surah (Chapter) Taha:

"مِنْهَا خَلَقْنَاكُمْ وَفِيهَا نُعِيدُكُمْ وَمِنْهَا نُخْرِجُكُمْ تَارَةً أُخْرَىٰ"

سورة طه الآية رقم (55)

That means "*God created the Man from the soil, and this Man will be reverted into this soil after death, and then God will raise him from it a second time*".

God has granted all living beings on this planet the inheritance of all sources of life and resources of nature. Therefore, I chose an area of specialization that involved the treatment and development of materials from nature since the environmental reactions will return the materials to nature through degradation and corrosion. On this note, I came up with the topic of this inaugural lecture, "Nature to Nature: The Mirage of Materials Longevity".

## 2.0 EVOLUTION OF ENGINEERING MATERIALS

The evolution of engineering materials is the foundation of technological progress, mapping directly from humanity's earliest use of natural substances to today's highly engineered, synthetic composites. Human eras are defined by dominant materials, which have continually expanded to offer greater strength, lighter weight, and unique functional properties. The history of engineering materials is a fascinating journey that reflects humanity's evolving understanding and utilization of various substances to meet practical needs. This evolution can be divided into several key periods, each characterized by significant advancements in material science and technology.

**2.1 Stone and Bronze Age (circa 3000BCE -1200BCE)**

Begins with humans using materials as found in nature (wood, bone, stone, bark, etc.), perhaps changing only the shape. Use of fire to change materials (first ceramics). Development of agriculture and pottery, improvement in tools, and establishment of trade routes. Interactions with native metals and smelting of tin and lead, redox reactions. Smelting of copper and the development of significant mining operations. Intentional alloying of copper to make bronze, the spread of technology from the Near East, and the necessity of long-distance trade routes to supply tin. Development of sophisticated casting technology, particularly in the Far East.

**2.2 Iron Age (circa 1200BCE – 500BCE)**

The development of iron smelting technology led to widespread upheaval, which led to the decline of bronze and the spread of iron as the dominant technology. Additional cultural milestones during the Iron Age include written language. Power shift from the Near East to the eastern Mediterranean, silver mines of Laurion financing ancient Greece. The rise and fall of the Roman Empire, financed by mines at Rio Tinto. Role of iron in military conquests. Development of wootz steel in India and Chinese cast iron.

**2.3 Middle Ages (500AD – 1500AD)**

A decrease in mining, materials, and technology during the "Dark Ages" decreased the supply of precious metals for coinage, which meant knights had to be paid in land, and led to the development of the feudal system. The agricultural revolution in Europe resulted from increased iron production for heavy ploughs and horseshoes. Role of Charlemagne in reestablishing commerce and centralized government. Role of the Catholic church: lead for stained glass, bronze for bells, which could also be melted down into cannon.

**2.4 Age of Exploration (1400CE – 1700CE)**

Major globalization, improved communication and transportation, driven in part by the quest for gold, silver, and spices. Blossoming of science during the Renaissance (Copernicus, van Leeuwenhoek), but a gulf between science and practical applications. Invention of the printing press, the importance of alloying to produce good type metal.

Large-scale demand for weapons drove the iron industry; large-scale mining operations required financing; first shareholder arrangements. Shortage of fuel for smelters and foundries; transition from charcoal to coal to coke. The role of Abraham Darby in mass-producing cast iron. Thomas Newcomen's development of the steam (atmospheric) engine was the first source of power that wasn't wind, water, or muscle.

**2.5 Industrial Revolution (1760 -1840)**

Reasons it began in England. James Watt and the first true steam engine; the use of new engines to mine more coal and produce cheaper iron. Rediscovery of cement/concrete; setting underwater allowed the development of the canal system. Development of railroads. Cast iron is the first new structural material in thousands of years. Development of glass technology to allow larger pieces and more windows. Concurrent developments in America: the copper boom in Michigan, corresponding with the invention of the telegraph.

**2.6 Modern Era (1940 1950 onward)**

Transition from iron to steel. Development of aluminium, reactivity series, and reasons that aluminium wasn't isolated earlier, concurrent development of reliable sources of electricity, Hall-Heroult method. Development of synthetic polymers, from South American rubber to celluloid to Bakelite; the role of global conflict in the development of synthetic rubber. Role of new materials in automobiles and airplanes. Semiconductors, transistors, and integrated circuits.

***Human interaction with and manipulation of materials is one of the longest stories in the history of our species. It is a richly compelling narrative that can serve as an entry point to introduce engineering students to history and non-engineers to materials science.***

## 3.0 MY CONTRIBUTION

My Contribution to material and metallurgical engineering with the use of nature (minerals or binding clay) to produce engineering materials and maintaining the products from returning to nature, or by developing new materials. I began my journey in the metallurgical industry, where I acquired knowledge in mineral processing, beneficiation of metal ores, and the economic benefits of utilising mineral resources for engineering applications and employment opportunities. In addition, I worked on some mineral processing and beneficiation research and supervised students when I joined academia.

**3.1 Processing and Beneficiation of Minerals and Metal Ores**

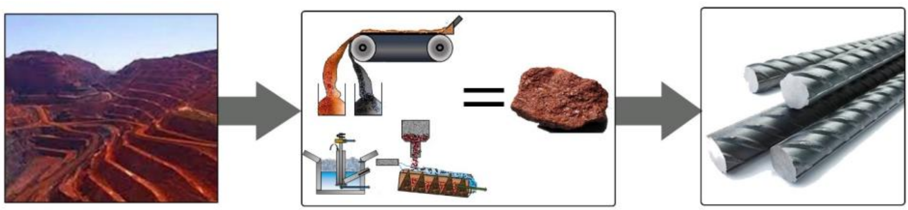
Nigeria is one of the richest countries in the world as far as mineral resources are concerned. The estimate of workable iron ore deposits stands at over 2.5 billion, among which hematite, hematite-magnetite, hematite-goethite, and siderite goethite grades are found in Itakpe. The goal of every mineral processing operation technique is to effectively separate the valuable materials from the gangue with minimum metal loss in tailing. Therefore, employing and developing a sustainable, effective, and relatively economical separation method is imperative. For hematite, the purpose of magnetizing is to reduce it to magnetite, and the reducing agents are usually C, CO and $H_2$. The reaction theory can be expressed as follows:

$$3Fe_2O_3 + C \rightarrow 2Fe_3O_4 + CO \uparrow$$

$$3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2 \uparrow$$

$$3Fe_2O_3 + H_2 \rightarrow 2Fe_3O_4 + H_2O \uparrow$$

The extraction and beneficiation of the metals from their ores required ore mining, separation and transformed into further suitable products as illustrated in Figure 1.



Mining the ore

Separating and concentrating the metal-containing compound

Reducing the ore to the metal

Figure 1: Main steps of metal extraction from their ores

Iron ore mining and separation techniques depend on the mineralogy and chemical composition of the ore deposit, necessitating careful selection to ensure effective iron liberation. Abdulrahman (2012) investigated the Agbaja iron ore deposits in Kogi State, Nigeria, using magnetic separation techniques. It was revealed by X-ray diffraction (XRD) that the ore contains principally goethite, with minor amounts of hematite, magnetite, siderite, kaolinite, and quartz, with an ore concentrate percentage of 76.67. In another work, Yerima and Abdulrahman (2015) conducted a physiochemical analysis of Chanchaga ore. The result showed that the most valuable metal in the ore is Cu, as shown in Figure 2, and other important metals such as Pt, Ag, Pb, and Cr are also present in very low concentrations.
The liberation size was established as 125 µm, 2.88 g /cm$^3$ was obtained as the average density of the ore, while the mesh of grind was 210 µm, and the median size was 50%.

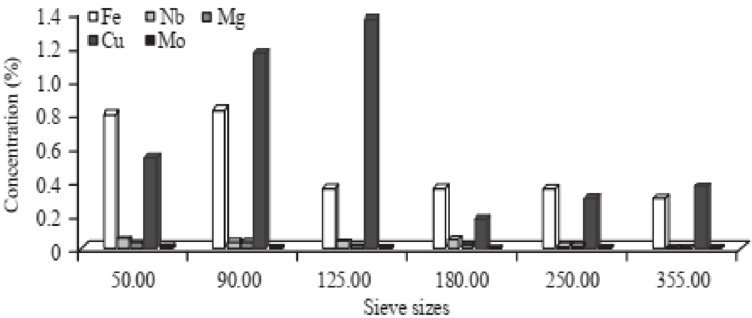



Figure 2: Concentration versus sieve sizes for various elements

Due to the importance of iron ore and steel in our national development, it has become imperative to consider the possibility of beneficiating low-grade locally available iron ore deposits for feedstock to the indigenous iron and steel plant located at Delta and Ajaokuta. This brought about the beneficiation of Ochokochoko iron ore that I supervised in 2016. The iron ore deposit is located between Jakura and Ochokochoko village, Lokoja Local Government Area of Kogi State, Nigeria. Figure 3 shows the XRD phase diffraction patterns of the peaks of the various mineral compounds of the ore sample from the five pits. From the diffractogram the iron mineral phases depicts the following: magnetite, goethite, hematite, quartz, ilmenite and siderite.

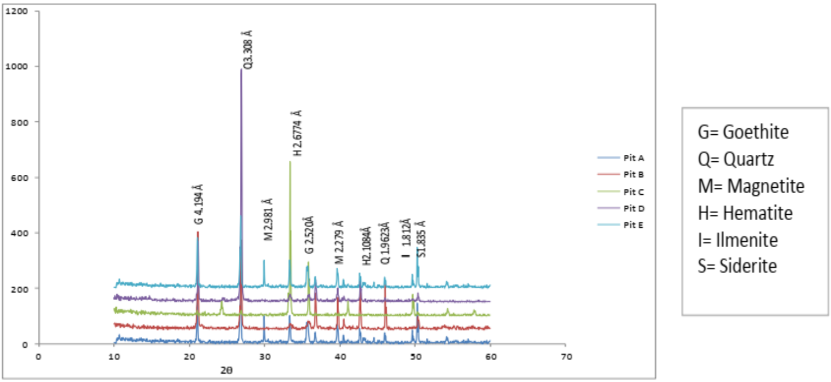



Figure 3: XRD analysis of the various pits of the Ochokochoko Iron Ore Sample

The iron bearing minerals are predominant when compared to other minerals in the matrix of the ore. (Agava *et al,* 2016). In addition, Abubakar, Ali and Abdulrahman (2020) also carried out the beneficiation of Magami ferruginous manganese ore with 13.1 % Mn elemental composition and the separation processes attained enrichment of 38.71 % Mn at a recovery of 29.1 % from 125 µm size using the shaking table, while 24.90 % Mn enrichment at a recovery of 69.44 % was obtained from magnetic separation. Therefore, the concentrates are typically suitable for manganese alloy or pig iron production by direct smelting.

Meanwhile, many of these ores investigated are not well exploited as a result of over-dependence on the oil and gas sector in Nigeria. The decline in the oil market necessitates the diversification of Nigeria's economy in mineral exploitation. The mining industry, accounting for only 0.3% of GDP, has not fully utilized its potential, leading to the importation of locally produced minerals. Ogwu, Abdulrahman, and other researchers in 2017 reported that Nigeria's mining sector contributes significantly to its GDP, not surpassing its 0.3%

contribution. Proper utilization could lead to national financial sufficiency and the development of indigenous products for export revenue. Since the clampdown of the Ajaokuta steel mill project, which was to utilise 2.2 × 10^6 tons of iron ore per year, mills have been built by private establishments, and they depend 100% on scrap steel, which is gotten from municipal solid waste (MSW) (Abdulrahman *et al.,* 2018). The study examined the feasibility of recycling as-rolled steel scrap for construction in Nigeria using steel products from various companies, and the yield strengths of 386 MPa, 410.77 MPa, and 391.27 MPa obtained from the samples are below the 420 MPa stipulated by SON, showing the steels are completely brittle due to the impurities and degradation nature of the scraps (Abdulrahman *et al.,* 2018). This resulted in the collapse of buildings due to steel reinforcement issues, overloading, stress, and concrete composition, which can lead to premature deterioration of untreated steels. This can be lethal to occupants and damage the construction company's reputation.

Mr. Vice Chancellor, Sir, to cap the experiences I acquired from ore extraction and mineral processing, one of our research works was patent in utilising Manganese ores extracted as cathode materials to produce alkaline batteries. However, the PhD research I am part of the supervisory team successfully developed a process route for the extraction of Yandoton-Daji gold Ore using Gravity and Pyrometallurgical methods. Run-of-mine ore samples collected from Bayan Banki village in Yandoton-Daji Tsafe Zamfara state, were subjected to mineralogical and geochemical characterization. At $1050^0$C extraction temperature, 40% borax dosage, and 60 seconds holding time, top purity of 90.11% gold was recovered, which equates to 22 carats gold. The findings affirm the efficacy of eco-friendly extraction of Yandoton-Daji gold ore using borax over the conventional toxic methods of gold extractions using cyanide and mercury (Abubakar, Muriana and Abdulrahman, 2024).

**3.2 Mineralogical composition and Binding properties of Clay and Concrete**

Soil, rocks, and minerals processed from nature are utilized in Mold-making, building construction, and bridge construction due to their strength, binding, and structural properties. Mr Vice Chancellor, Sir, Clay and concrete are part of the soil utilized to construct buildings, bridges, casting mould, and aesthetics. Clay materials, such as foundry sand, are crucial for metal casting due to their refractory nature and chemical stability. Clay bindings are used to create moulds for ferrous and nonferrous metals, providing cohesion, strength, and shape retention. (Abolarin, Lawal and Abdulrahman, 2010). The moisture content and moulding properties of Tudun-Wada clay from River Niger sand, a refractory material with high alumina content was investigated. The sand properties, affected by the moisture content and other factors, as shown in Table 1, were suitable for foundry moulding operation of ferrous and non-ferrous alloy casting of parts (Abolarin *et al.,* 2010).

Table 1: Properties of Mold Sand Mixtures with 12% Clay

| Water % | 1 | 2 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|---|
| Green compression strength | 11.1 | 9.2 | 6.8 | 4.9 | 4.7 | 4.2 |
| (psi) (kN/m$^2$) | 76.59 | 63.48 | 46.92 | 33.81 | 32.43 | 28.98 |
| Green shear strength (psi) | 1.2 | 1.1 | 0.6 | 0.5 | 0.3 | 0.2 |
| (kN/m$^2$) | 8.28 | 7.59 | 3.6 | 3.45 | 2.07 | 1.38 |
| Dry comprehension strength | 62 | 73.5 | 465 | 467.5 | >467.5 | >467.5 |
| (psi) (kN/m$^2$) | 427.8 | 507.15 | 3208.5 | 3225.75 | >3225.75 | >3225.75 |
| Dry shear strength (psi) | 8.5 | 22 | 110 | 140 | 205 | 230 |
| (kN/m$^2$) | 58.65 | 151.8 | 759 | 966 | 1414.5 | 1587 |
| Permeability (mmws) | 280 | 360 | 420 | 350 | 300 | 260 |

In another research I supervised, the effect of steel machining chips as an additive on the properties of clay obtained from Bida, Niger State, revealed the highest crushing strength with 10 wt% steel chips, as shown in Figure 4 (Anunuso, Abdulrahman, Essien and Agonga, 2019). It was observed that at a temperature of 1050 ºC, the linear shrinkage decreases with additions of steel machining chips from 2.40% to 2.28% and increases in the crushing strength from 256.41 kg/m2 to 394.74 kg/m2 without changing the properties of the clay. This result proves the viability of using steel machining chip powder as an additive to clay to enhance its engineering properties for advanced usage.

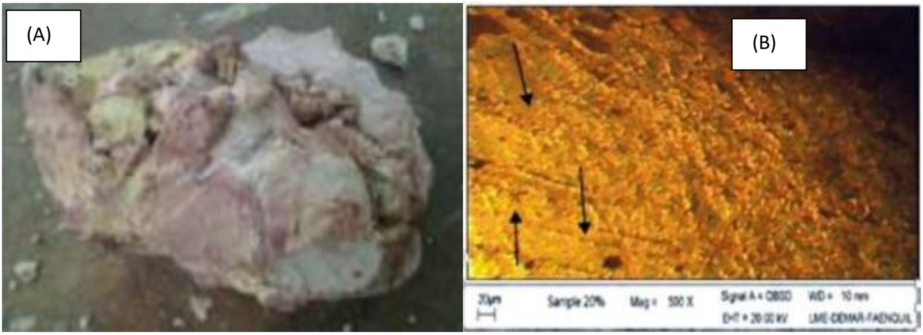



Figure 4: (A) Pictorial View and (B) SEM Photograph of Clay with 10Wt% steel chips

However, Concrete is the most widely used construction material in many ancient structures and industries. Cement is one of the major and non-removable components of concrete. Concrete is a robust material that is generally a compound of cement, Aggregates (coarse aggregate such as limestone plus a fine aggregate such as sand), Water, and Chemical Admixtures (superplasticizers, retarders, corrosion-inhibiting chemicals). In one of my research works, I reported that the characteristics of cement paste, mortar, and the resultant concrete greatly depend on the mineralogical composition, the microstructure of the cement, and the supplementary cementitious materials. The study examined the impact of pulverized burnt clay (PBC) and palm oil fuel ash (POFA) on water demand and high-range water-reducing admixture requirement in self-consolidating high-performance concrete paste. The results revealed that POFA, OPC, and PBC have BET surface areas of 23.7514 $m^2/g$, 5.0670 $m^2/g$, and 2.9791 $m^2/g$, respectively. Although PBC has the lowest BET surface area, XRD results shown in Figure 5 revealed that it contains the highest quartz and glassy substances, which make it a flow-enhancing material (Ismail *et al.,* 2013).

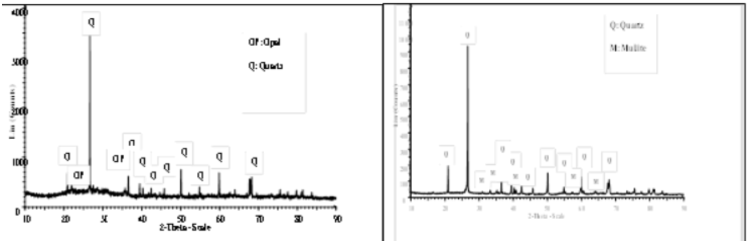



Figure 5: X-ray diffraction Pattern of (a) POFA, (b) PBC

As a result of these properties observed with concrete, a generally good material mixture used in construction and some areas of fabrication, the cement paste in concrete is alkaline with a pH typically between 12 and 14. This paste forms a passive film surrounding reinforcing steel in concrete, which further thickens the iron oxide layer on the steel surface. Many researchers believe this alkaline environment facilitates the passive protective film around the steel (Ismail and Abdulrahman, 2011). However, the passive film is not invulnerable, though it can be damaged chemically and mechanically. Some examples of chemical damage are carbonation, chloride ingress (seawater, de-icing salt, unwashed sea sand, admixtures etc.) and sulphate attack. As a result of this attack, the reinforced steel is subjected to premature failure due to the corrosion of the steel. Sumadi *et al.* (2012) utilised fly ash concrete as an alternative to corrosion attack of reinforced steels in the construction world by comparing its properties and effects with regular concrete. It can be observed that the higher the age (days), the higher the strength of the composite produced from fly ash as shown in Figure 6. But yet, the solution does not stop the corrosion of the steels.

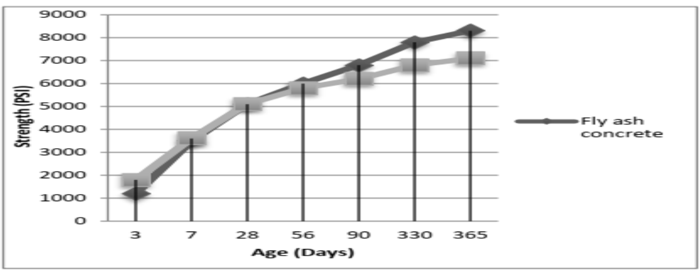



Figure 6: Strength of Fly Ash Concrete

### 3.3 Corrosion of Metals and their Control Measures

Corrosion is an electrochemical process that slowly damages metallic structures and thermodynamically returns them to their stable state in identical compounds, with removal proportional to current flow (Abdulrahman *et al.,* 2015). Corrosion causes damage to materials used in automobiles, bridges, pipeline systems, buildings, petroleum refineries, etc. The damage is chemically induced on a metal (shown in equation 1), leading to the deterioration of its properties and failure under construction. The failure of mild steel as a construction material can harm human health and the economy.

$$2Fe^{2+} + 2OH^{-} + 2NO_2 = 2NO + Fe_2O_3 + H_2O + Fe^{2+} + OH^{-} + NO_2 = NO + \gamma - FeOOH \quad (1)$$

In order to tackle the menace associated with corrosion, proper treatment, design, and preparation of concrete following the required standards and timely maintenance of the structures under those conditions would guarantee them a long and efficient life in aggressive media. Our research utilized the Taguchi L9(32) orthogonal array method to optimize the process parameters of maize-stover ash potash (MSAP) as a quenching medium for heat treatment of AISI-1020 steel. The optimal factor level of MSAP solution strength was achieved at AM1BM1, which offered 57.6 HRC hardness, 39 J toughness, and 1971 $N/mm^2$ tensile strength as improved mechanical properties for the heat-treated steel (Ogunwede *et al.,* 2020). However, most treatment and design studies in the literature and research in reinforced concrete assumed that the durability of reinforced concrete structures could be taken for granted. Hence, many supported concrete structures are exposed during their lifetimes to environmental stress (corrosion and expansive aggregate reactions), which attacks the steel reinforcements (Abdulrahman *et al.,* 2011).

This natural phenomenon has recently attracted the attention of many scientists and engineers, especially in Nigeria, where the collapse of buildings frequently occurs. To improve the durability of reinforced steel in an aggressive environment, sustainable and hazard-free protection measures are considered to salvage the service life of steel reinforcement in concrete structures. Among the control measures of corrosion are cathodic protection, inhibitors, coatings, penetrating sealers, heat treatment, and chloride removal (Abdulrahman and Ismail, 2012), and the development of composite or alloy materials to improve the longevity of the materials used in aggressive media. Abdulrahman *et al.,* (2011) reported information related to the basic corrosion protection methods to extend the service life of reinforced concrete structures, including inhibitors, sealers, and barriers. The study suggests using corrosion inhibitors in concrete preparation to control corrosion, but it lacks information on their effects on concrete's mechanical and physical properties due to different environmental conditions.

**3.4 Corrosion Protection with Green Inhibitors**

The corrosion inhibitor is one of the most widely applied protection measures I have applied because of its simplicity in applications, environmental friendliness, and relatively less expensive. A corrosion inhibitor is a chemical substance that, when added in a required amount to a corrosive environment, decreases the rate of corrosion in aggressive environments. Corrosion inhibitors can be either inorganic or organic (green) inhibitors. The inorganic ones that are synthetic in nature are formed from various inorganic compounds such as molybdates, chromate, phosphates, etc., which are less costly but have a great destructive effect on the environment. The cost of inorganic inhibitors is relatively low, but many effective inhibitors, such as chromate, mercride, and arsenate, are very toxic (harmful to humans and the environment). Corrosion inhibitors frequently work as anodic, cathodic, or mixed inhibitors by adsorbing themselves on the metallic surface (physical adsorption) by forming a film layer on the surface. Inhibitors reduce corrosion activities by: (1) increasing the cathodic and anodic polarization behaviour, (2) decreasing the mobility of ions to the surface of the metal, (3) raising the electrical resistance of the metallic surface, (4) creating a barrier film on the surface of the metal. Introducing inhibitors to concrete improves the quality and integrity of reinforced steel. Most authors agree that reinforcement corrosion is the most important cause of premature failure of reinforced concrete structures worldwide and generates a great research concern due to its effects on the global economy. Figure 7 shows the corrosion reaction of concrete.

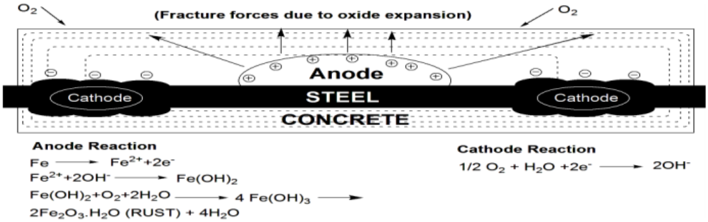



Figure 7: Corrosion Process for Steel in Concrete (Source: Ismail *et al.,* 2015)

Some external factors, through the following environmental parameters, promote electrochemical reaction in the reinforced concrete. These include oxygen and Moisture Availability at the Rebar Level, Relative Humidity and Temperature, Entry of Acidic Gases, Pollutants, and Carbonation to the Rebar Level, Stray Currents, and Bacterial Action.

Over the years, abundant noxious weeds have been identified as more useful for corrosion applications due to active compounds with antioxidant activities, such as chlorophylls and carotenoids, phenols, saponin, alkaloids, glycoside, terpenoids, and amino acids. Plant extract corrosion inhibitors are cheap, non-toxic and environmentally friendly. The yield of these compounds and the corrosion inhibition abilities vary widely depending on the part of the plant and its geographical location. Efficiency is justified by the phytochemical compounds present therein, with molecular and electronic structures bearing close similarity to conventional organic inhibitor molecules.

Efforts have been made by several researchers and regulatory bodies to solve the problem of sulphate attack on concrete to no avail with existing organic and inorganic inhibitors. Hence, Abdulrahman *et al.* (2011) investigated the uses of hydrophobic green plant extract Bambusa Arundinacea to inhibit sulphate and chloride attack on concrete and compressive strength of 100×100×100mm concrete cubes after 7, 28, 90, and 180 days of curing test was utilised. The results of the inhibitors studied showed that Bambusa Arundinacea has superior compressive strength compared to calcium nitrite and ethanolamine, as shown in Tables 2 and 3.

Table 2: Compressive strength test (MPa).

| System studied | 7 Days | 28 Days | 90 Days | 180 Days |
|---|---|---|---|---|
| Control | 30.83 | 43.27 | 54.87 | 41.31 |
| Contaminated by $MgCl_2$ | 39.34 | 48.22 | 51.90 | 43.80 |
| $Ca(NO_2)_2$ inhibitor | 47.89 | 60.70 | 48.87 | 44.35 |
| $C_2H_7NO$ inhibitor | 45.65 | 49.58 | 70.98 | 72.09 |
| *B. arundinacea* inhibitor | 47.29 | 51.91 | 68.40 | 78.09 |

Table 3: Compressive strength test (MPa) for 0.45 and).65 W/C ratio of 1.5% MgSO4 additions,

| System | 7days | | 28 days | | 90 days | |
|---|---|---|---|---|---|---|
| | 0.45 W/C | 0.65 W/C | 0.45 W/C | 0.65 W/C | 0.45 W/C | 0.65 W/C |
| Control | 27.87 | 20.59 | 39.07 | 34.90 | 51.53 | 37.83 |
| 2% calcium nitrite inhibitor | 40.80 | 26.50 | 48.30 | 38.37 | 54.55 | 39.62 |
| 4% calcium nitrite inhibitor | 47.82 | 19.80 | 52.51 | 31.23 | 49.85 | 35.00 |
| 2% ethanolamine inhibitor | 42.91 | 18.17 | 56.69 | 33.73 | 56.80 | 39.85 |
| 4% ethanolamine inhibitor | 38.53 | 17.51 | 51.04 | 31.61 | 54.90 | 36.28 |
| 2% green Bambusa arundinecea inhibitor | 35.52 | 19.09 | 48.36 | 28.81 | 58.92 | 31.91 |
| 4% green Bambusa arundinecea inhibitor | 33.71 | 18.19 | 45.58 | 27.55 | 58.43 | 30.86 |

Bambusa Arundinacea can be considered a better substitute for nitrite and amine-based corrosion-inhibiting admixtures for durable concrete structures due to its pore-blocking effects. In other studies, Abdulrahman and Ismail (2011) and Abdulrahman and Ismail (2012) considered this plant extract as a passivation-promoting inhibitor for reinforced concrete samples contaminated with $MgCl_2$. The corrosion parameters of the inhibitors using Electrochemical impedance spectroscopy (EIS), linear polarization resistance (LPR) showed that *Bambusa Arundinacea* is superior as compared to calcium nitrite because of its high concrete resistivity, chloride binding property, and polarization resistance, as shown in Table 4. Therefore, Eco-friendly green inhibitors have been utilized to enhance the properties of concrete contaminated with sulphate and chloride compared to existing inhibitors (Abdulrahman and Ismail, 2011; Ismail and Abdulrahman, 2016).

Table 4: Measurement of corrosion rate by EIS and LPR technique.

| System studied | Time (Days) | LPR | | | | EIS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $R_c$ (KΩ) | $R_p$ (KΩ) | $I_{corr}$ (μA/cm$^2$) | C.R ($10^{-3}$ Mmpy) | $C_{dl}$ (mF) | $R_c$ (kΩ) | $R_p$ (kΩ) | $I_{corr}$ (μA/cm$^2$) | C.R ($10^{-3}$ Mmpy) |
| Control | 180 | 4.10 | 170 | 0.1525 | 1.80 | 0.112 | 3.97 | 142 | 0.1883 | 2.19 |
| Contaminated by $MgCl_2$ | 180 | 3.42 | 130 | 0.2008 | 2.30 | 0.133 | 3.44 | 120 | 0.2179 | 2.50 |
| $Ca(NO_2)_2$ inhibitor | 180 | 3.46 | 226 | 0.1153 | 1.30 | 0.115 | 3.64 | 138 | 0.1883 | 2.19 |
| $C_2H_7NO$ inhibitor | 180 | 4.41 | 136 | 0.1916 | 2.20 | 0.106 | 4.33 | 150 | 0.1735 | 2.02 |
| *B. arundinacea* inhibitor | 180 | 5.71 | 202 | 0.1285 | 1.50 | 0.080 | 5.73 | 198 | 0.1312 | 1.53 |

Meanwhile, the water permeability resistance and microstructure of reinforced concrete treated with *Bambusa arundinacea* as a green corrosion inhibitor were reported by Abdulrahman *et al.* (2013). Bambusa arundinacea inhibited differential aeration of cells, preventing corrosion on steel surfaces. Calcium nitrite and ethanolamine inhibitors did not reduce ettringite and Friedel's salt formations in chloride-contaminated concrete paste. Only Bambusa arundinacea buffered pore structures. Finally, Abdulraman and Ismail, (2014) evaluated the corrosion inhibition of green inhibitors on the crystal structures of carbonated concrete shown in Figure 8. Three inhibitors used were: calcium nitrite, ethanolamine, and eco-friendly green *Bambusa Arundinacea*.


(a)


(b)

Figure 8: Accelerated Carbonation for 2% (a) and 4% (b) $Ca(NO_2)_2$ inhibited sample for 0.45 w/c of 1.5% $MgCl_2$ Contamination

The concrete mix, designed at 30 MPa with 0.45 W/C ratios, was contaminated with chloride and 2% and 4% cement content, respectively. The Bambusa arundinacea inhibitor showed the lowest carbonation level, as shown in Figure 9, forming an impermeable barrier against $CO_2$ gas. It also caused the saturation of portlandite, maintaining a Ca/Si ratio above 1.65.

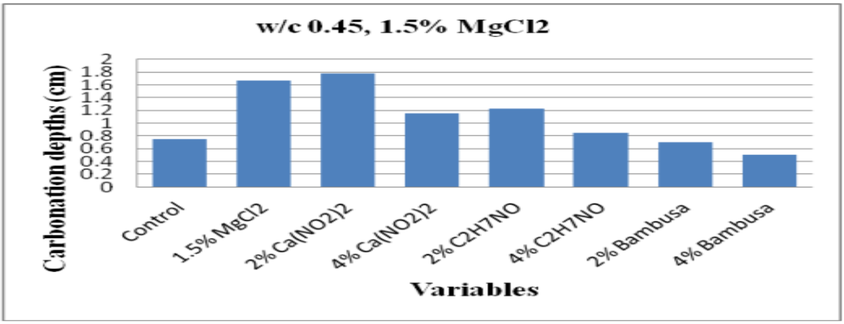



Figure 9: Carbonation depths of accelerated carbonated samples for 1.5% $MgCl_2$ contamination of 0.45w/c

Other potential green corrosion inhibitors to reduce mild steel dissolutions in various aggressive mediums are shown in Table 5 with their inhibitive behaviours and different corrosion measurements adopted for corrosion inhibition.

Table 5: Plant Corrosion Inhibitors with their Inhibitive Properties

| S/N | Applied Inhibitors | Corrosion Measurement Techniques | Findings | References |
|---|---|---|---|---|
| 1 | Bambusa Arundinacea *in 1M HCl* | Weight loss | The inhibition efficiency of 72.84% at 10% v/v extract concentration for 72 hours exposed time for Bambusa arundinacea was achieved. Adsorption of the inhibitor molecules on mild steel strip surfaces was consistent with Langmuir adsorption isotherm. | Abdulrahman *et al.,* 2007 |
| 2 | solid waste (Genus Musa, Genus Saccharum and Citrullus Lanatus) in 1M HCl | weight loss technique | The inhibition efficiency of 69.60%, 68.41%, and 58.15% at 10% v/v of extracts concentration for 72 hours exposed time for Genus saccharum, Citrullus lanatus and Genus musa, respectively, were achieved. | Ismail et al., 2011 |
| 3 | effect of vernonia | weight loss technique | The inhibition efficiency and degree of surface coverage | Eyu et al., 2013 |

| | | | | |
|---|---|---|---|---|
| | amygdalina extracts on corrosion inhibition in 3.5wt% NaCl solution | | determined from the study revealed that the inhibitory actions of the inhibitor increase with increased dosage, the most suitable inhibitor concentration was found in 6% v/v with an inhibition efficiency of 75%. | |
| 5 | *Citrus aurantifolia* seed extract in $H_2$ $SO_4$ Solution | Weight Loss | The inhibition efficiency was found to increase with an increase in citrus *aurantifolia* (lime) seed extracts but decreased with temperature rise. The values of the free energy of adsorption up to -20KJ/mol, which is indicative of physical adsorption between charged molecules and a charged metal | Ajani et al., 2014 |
| 6 | Bitter leaf (*Vernonia amygdalina*) root extract in 1.5 M Sulphuric acid solution | Weight loss, Hydrogen evolution and Thermometric measurements | The inhibitor exhibits excellent inhibition efficiency on mild steel corrosion as 90 %, 84.82 %, 79.65 % and 76.90 % of inhibition efficiency achieved with the addition of 0.5 g/l concentration of bitter leaf root extract (BLRE) at 30°C, 40°C, 50°C and 60°C temperature respectively. | Awe et al., 2015 |
| 7 | *Moringa oleifera in 1M H2SO4* | Weight loss | An inhibition efficiency of 83% for an exposure time of 12 hours was obtained at 25 oC. Thermodynamic considerations indicate that the adsorption of the extract is exothermic and spontaneous | Abdulrahman et al., 2015 |
| 8 | Camel foot leave extracted in 1.5M hydrochloric | weight loss and hydrogen evolution measurement | The inhibition efficiency obtained from weight loss and hydrogen evolution measurement at 60 °C with the addition of 0.5 g/l concentration of CFLE was 64.08% and 62.12%, respectively. The thermodynamic adsorption parameters (△Hads, △Sads, △Gads) showed that the studied inhibitor is adsorbed on a mild steel surface by a physical adsorption mechanism, accompanied by an exothermic reaction and spontaneous process. | Kobe *et al.,* 2016 |

## 3.5 Corrosion protection of Buried Pipe and Tanks

Subsurface pipeline systems are the most reliable, cost-effective and efficient means of transporting massive amounts of liquid and gaseous products. Meanwhile, the buried pipeline system has experienced a considerable number of unforeseen degradations and deterioration, resulting in pipeline failure over the years. Pipeline corrosion is extremely complicated and is affected by practically every physical, chemical, and biological parameter in water distribution systems. Due to the detrimental effect of damage induced by seawater in pipeline structures, there is a need to investigate the effects of natural seawater and air environments on the mechanical properties of representative pipeline materials, to obtain useful data for the estimation of their service lives. Hence, Adedipe *et al.,* 2023) utilized a X70 steel pipeline plate and welded it using the submerged arc welding technique and subjected it to air and natural seawater environments. Test specimens were soaked in seawater for twelve months at 28 ºC. The study evaluated the mechanical properties and fracture surfaces of parent plates, weld regions, and heat-affected zones. Results showed tensile strengths of 634.00 MPa and 674.00 MPa, compressive stresses of 750.10 MPa and 750.40 MPa, and brittle and ductile failure mechanisms. Though soil-soluble ions speed up the rate of corrosion, sulphate ions were found to have a greater influence. Furthermore, the corrosion rate of steel buried underground is also time-dependent. The correlation of soil parameters (soluble Ions and Oxygen) on the corrosion rate of buried low-carbon mild steel A106 specification was investigated. Six mild steel samples were buried in soil samples obtained from Gidan Kwano, Minna, Niger State. Each sample was exhumed at 14-day intervals to study the influence of soil properties on metal loss via the weight loss method over time. Results in Table 6 showed that both parameters had an influence on buried steel, but soil sulphate also contributed to corrosion of the steel (John, Abdulrahman, and Akintunde, 2018).

Table 6: Evaluation of A106 Steel Sample Results

| Coupon | Hours | Initial weight | Final weight | Weight loss | Corrosion rate ($g/cm^2/hr$) x $10^{-2}$ | Corrosion rate (g//hr) x $10^{-3}$ | Corrosion rate /area/hr (g) x $10^{-6}$ |
|---|---|---|---|---|---|---|---|
| 1 | 336 | 38.6 | 38.5 | 0.1 | 6.2 | 1.19 | 3.55 |
| 2 | 672 | 39.8 | 39.6 | 0.2 | 6.1 | 1.17 | 1.75 |
| 3 | 1008 | 41.1 | 40.6 | 0.5 | 9.8 | 1.89 | 1.87 |
| 4 | 1344 | 40.4 | 39.8 | 0.6 | 8.9 | 1.71 | 1.27 |
| 5 | 1680 | 43.3 | 42.4 | 0.9 | 10.0 | 1.92 | 1.15 |
| 6 | 2016 | 39.6 | 38.5 | 1.1 | 11.1 | 2.14 | 1.06 |

In another research, the effects of soil parameters (moisture content, soil resistivity, soluble ions, and oxygen) were established on the corrosion rate of low-carbon steel in the soil of Gidan Kwano, Minna, Nigeria. The site had a moisture content of 23.73% and a resistivity of 33.4 ohms per meter. The weight loss and corrosion rate increase with an increase in the exposure periods (Alamu, Abdulrahman, and Essien, 2018; John Abdulrahman and Akintunde, 2018). This indicates buried pipelines face corrosion due to aggressive soil, varying climates, microorganisms, and stray currents, making inhibitors less effective. A viable solution is needed to combat this issue. Abdulrahman *et al.* (2015) applied Cathodic Protection system using the impressed current technique as shown in Figure 10 to mitigate corrosion of a buried steel pipeline.

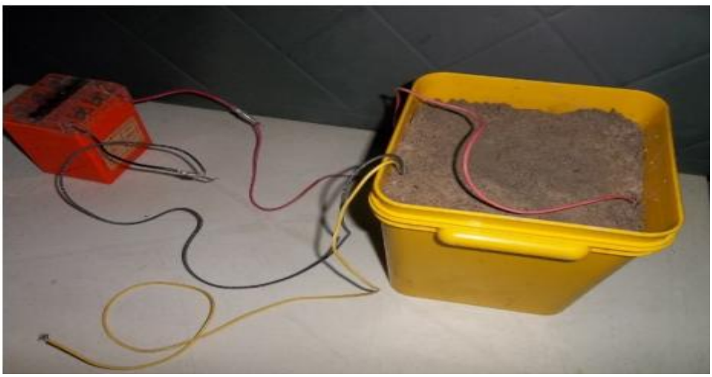


Figure 10: Impressed current cathodic protection setup

The study validated theoretical work by conducting a soil test with a pH of 6.97 and resistivity of 7850 ohm$^{-cm}$. The soil samples were found to be mildly corrosive and non-aggressive towards mild steel pipelines. Cathodic protection was found to be a viable corrosion control measure, reducing corrosion rates and concentrating it at another location. Abdulrahman *et al.* (2011) reported combination of inorganic and surface coating applications to reinforced rebar and pipes could reduce the corrosion rate drastically. Recently, nano-coating or nano-composite materials were developed to protect steel against corrosion of buried pipes and tanks. Buhari *et al.* (2019) and Buhari *et al.,* (2022) synthesized Cobalt-Molybdenum supported with magnesium oxide (Co-Mo/MgO) catalyst yield in the production of multiwall carbon nanotube (MWCNT). Wet impregnation was used to synthesize a Co-Mo/MgO bimetallic catalyst and carbon nanotubes using a CCVD reactor. The catalyst was optimized using techniques, yielding 93.22% and 40.62% respectively. XRD analysis shown in Figure 11 further revealed graphitized carbon formation with higher intensity peaks, while the 45.21o peak was typically crystalline or amorphous.

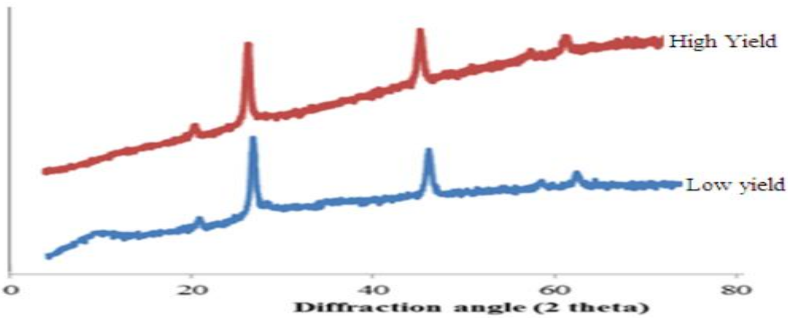



Figure 11: XRD spectral of the developed CNTs

The mechanical and anti-corrosive capabilities of the optimal CNTs and epoxy resin coating were examined on steel tanks. Soil samples with high ions content showed chloride (272 mg/kg), sulphate (467.20 mg/kg), and resistivity values of 167.40 Ω-m. Acidic pH (6.11–7.48), CNTs increased tensile strength, hardness, and modulus, with 3.5%

CNTs being the best. The EIS investigation in Figure 12 showed that the nanocomposite coatings demonstrated significantly superior conductors. Thus, the hybrid of epoxy and CNTs enhance the hydrophobicity of the coated surface (Buhari *et al.,* 2023).

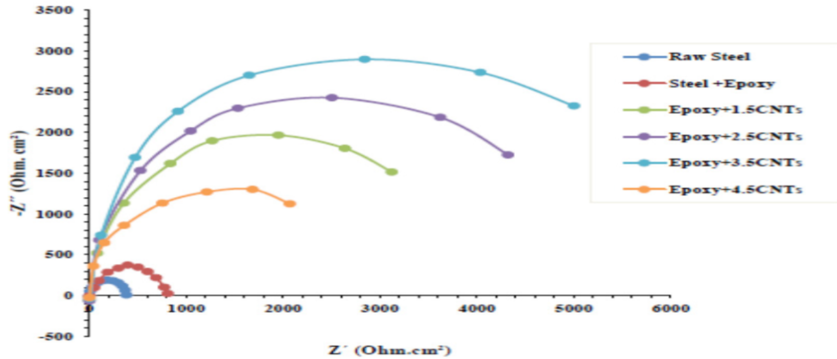



Figure 12: Nyquist plots of carbon steel coated with epoxy and different concentrations of CNTs

In another study, Kareem, Abdulrahman, Abdulkareem and Tijani, (2020) synthesized via green route using $SnCl_2.2H_2O$ and *Euphorbia trigona* (African cactus) plant extract as precursors. Figure 13 show the green route process optimized parameters for producing for the production of nanocomposite.

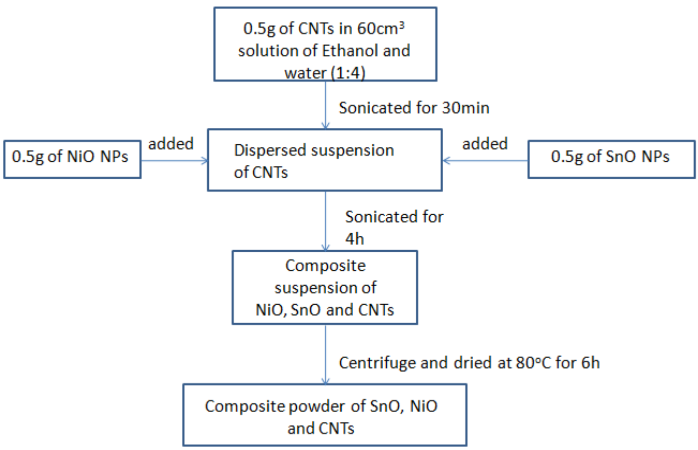



Figure 13: Synthesis of NiO-CNTs-$SnO_2$ (1:1:1) Nanocomposite

The tetragonal cassiterite phase was optimized for pH 10, precursor concentration, and synthesis temperature. The NiO-CNTs-$SnO_2$ nanocomposites coatings on AISI 1020 steel showed improved anti-corrosion properties shown in Figure 14, with a lowest corrosion rate and 93.30% corrosion protection efficiency shown in Table 7.

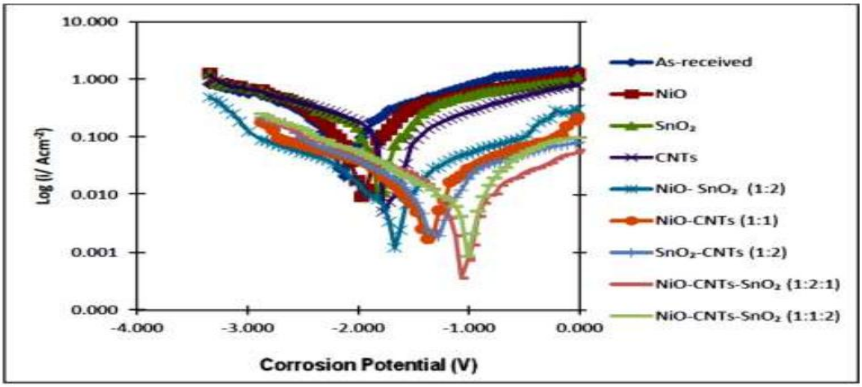
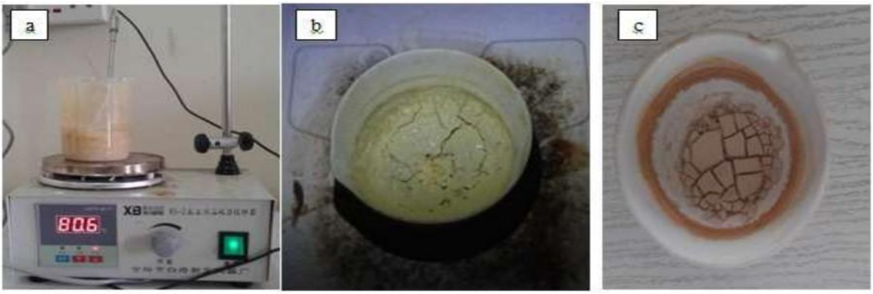



Figure 14: Tafel Graph of the Combined Samples

Table 7: Potentiodynamic Polarization Parameters for Nano-coating of AISI 1020 Carbon Steel in Soil

| Experimental Sample | Ecorr (V) | Icorr($A/cm^2$) | CPE. % | CR (mpy) |
|---|---|---|---|---|
| As-Received | -2.15 | 0.0955 | | 0.0335 |
| NiO | -1.73 | 0.0286 | 70.05 | 0.0100 |
| $SnO_2$ | -1.71 | 0.02521 | 73.60 | 0.0088 |
| CNTs | -1.69 | 0.0221 | 76.86 | 0.0077 |
| NiO- $SnO_2$ (1:2) | -1.67 | 0.0162 | 83.04 | 0.0057 |
| NiO-CNTs (1:1) | -1.40 | 0.0146 | 84.71 | 0.0051 |
| $SnO_2$-CNTs (1:2) | -1.15 | 0.0111 | 88.38 | 0.0039 |
| NiO-CNTs-$SnO_2$ (1:2:1) | -1.10 | 0.00973 | 89.81 | 0.0034 |
| NiO-CNTs-$SnO_2$ (1:1:2) | -1.05 | 0.0064 | 93.30 | 0.0022 |

Furthermore, Abdulrahman *et al.* (2024) patent work on NiO-CNTs-$SnO_2$ Nanocomposites Coatings on AISI 1020 Steel, Application and Preparation Process Therefor. The study reveals that NiO-CNTS-$SnO_2$ nanocomposites shown in Figure 15, with spherical, tubular, and cubic structures, have improved anti-corrosion properties.




**(a)** Figure 15: Scaled Nanocomposite Coatings (b) Purified Dried Nanocomposite Coatings (c) Calcined Nanocomposite Coatings

Finally, oil extracted from a sustainable, biodegradable vegetable oil (Jatropha Cucas), has been tested for its suitability as a lubricant substitute. The oil's physicochemical, rheological, temperature, thermo-oxidative stability, and corrosion properties were compared to the commercially available mineral oil base lubricant (SAE 20W50). Jatropha oil showed better viscosity index than SAE 20W50, with good corrosion inhibition properties but poor cold flow and flash point (Woma, Lawal, Abdulrahman, and Olutoye, 2019; Woma *et al.,* 2019).

### 3.6 Structural Improvement of Metals and Development of Composite Materials

Advanced engineering materials are crucial for transportation, aerospace, and military applications due to their lightweight, corrosion, wear, fatigue resistance, and high stiffness, making composite materials the best solution. Composites are materials made by combining distinct phases, arranged or distributed, with unique characteristics. They consist of a reinforcement or filler embedded within a matrix, providing shape, surface appearance, and durability, while fibrous reinforcement carries structural loads (Abdulrahman and Haruna, 2015). A composite material usually has characteristics that are not depicted in monolithic materials. Haruna, Abdulrahman *et al.,* (2014) reviewed the prospects and challenges of composites in developing countries. The application of composites in manufacturing and biomedical industries has revealed the availability of local resources for technological advancement.

Mr. Vice Chancellor, Sir, I have developed composite brake pads that are non-injurious to human health and do not corrode any parts of the brake pad assembly, and I also supervised students in this area. One of the achievements of the composite is the production of automobile brake pads from available agricultural waste. Abdulrahman *et al.* (2020) utilised palm kernel shell (PKS), coconut shell (CNS), and Canarium sweinfurthii shell (CSS) powder for asbestos-free brake lining materials production to mitigate health concerns which cause cancer. The brake lining production process utilized powders and fillers, revealing increased water and oil absorption, increased compressive strength, and an acceptable coefficient of friction. The CSS powder, when mixed with fillers, is a promising material for brake lining applications.

In 2019, automobile brake pad compositions, processing, materials properties, and production from agricultural waste and Nigerian gum Arabic binder were reviewed. Agro-based materials like plant fibres, cashew nut shells, and Nigerian Gum Arabic are effective alternatives for asbestos and resin components in brake pad production (Lawal *et al.,* 2019; Lawal *et al.,* 2019). Haruna, Abdulrahman, Abolarin and Muriana, (2019) developed a new brake pad using sheanut shell (SNS) as the reinforcement and epoxy resin as the binder, shown in Figure 16. The study used calcium carbonate, graphite, and aluminium oxide in five compositions with epoxy resin and reinforcement. Results showed decreased compressive strength, abrasive strength, and density with increased water absorption rate. Research indicates that SNS particles can replace asbestos in brake pad production, with compressive strength ranging from 64.88 - 93.04Mpa, and increased water absorption rate.

A B C

Figure 16: Mixing of the constituents (A), Produced Samples (B), Sheanut Shells (C)

It is observed the wear rate reduced as the reinforcement content increased as shown Figure 17. This may be due to better interfacial bonding between the reinforcement and the matrix causing good surface property.

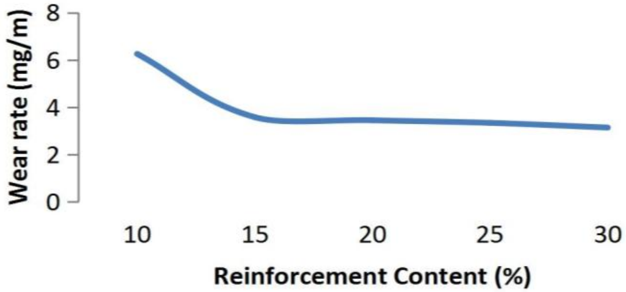



Figure 17: Variation of Wear Rate with Reinforcement Content

Also, a study involving coconut shells and seashells found that coconut shell-based composites showed superior mechanical and tribological properties compared to seashell-based samples (Abutu *et al.,* 2019).

**3.7 Development of Biomaterials and Biocomposites**

In recent years, scientists have become increasingly concerned about the non-biodegradability of synthetic polymer composites and their impact on the environment. Recycling and repurposing polymers like LDPE can be challenging due to their components and environmental impact, making immediate disposal in landfills or incinerators undesirable (Abdulrahman and Haruna, 2015).

The applications of green composites are diversified into the engineering end uses mainly for non-structural applications such as interior automobile components, packaging, building, and insulation materials. I also supervised students on the development of numerous biocomposites from agricultural waste materials. In 2014, building resilient materials for concrete composites was developed from agro-waste obtained from Kakuri (Kaduna State), Obudu (Cross rive) and Kwakuti (Niger State), as shown in Figure 18. The X-Ray Fluorescence, FTIR analysis on the three samples from Kwakuti showed the highest silica content of 70.30%, and the band at 3425cm$^{-1}$ assigned to O – H stretch of the hydroxyl groups (adsorbed water) (Ubi *et al.,* 2018). The uncrushed luffa fibre composites had a maximum tensile and flexural strength of 7.65 MPa and 17.08 MPa, respectively, corresponding to a young modulus and flexural modulus of 21.08 MPa and 232.22 MPa for the 8% and 4% wt. NaOH concentration, respectively (Ubi and Abdulrahman, 2015).


Figure 18: Different categories of Rice Husk and Composite Produced

Abdulrahman and Haruna (2015) also established that 5 to 25 wt% eggshell particles (ESP) of size 75µm were added to the polymer as reinforcement, which improved the tensile strength with the maximum value of 19.43 MPa at 10 wt% ESP; the Young's modulus has a maximum value of 100 MPa at 20 wt% filler content. Meanwhile, using luffa cylindrica fibre as a reinforcing material for the development of green composites showed the highest impact energy of 6.425 J, and a bulk density of 1.67 g/cm3 was obtained for the 9:1 (matrix to filler ratio) samples (Abdulrahman *et al.,* 2015). This showed fibres reinforced materials usually exhibit excellent mechanical properties. As a result, vulcanized natural rubber composites were prepared using cellulosic nanoparticles obtained from bamboo (BNC), coconut husk (CHNC), cotton linter (CLNC), and carbon black (CB) as reinforcing material/fillers. It was established that CHNC composites showed a trend of increase in tensile strength from 1.8 to 3.82 MPa with filler loading of 0 to 25 weight%, while bamboo, cotton linter, and carbon black-based nanocomposites gave their highest values of 3.16, 3.92, and 4.50 MPa, respectively at a filler content of 30 weight% (Oboh *et al.,* 2017). The study found that increasing CFNP loading from 0 to 25 parts per hundred rubber (pphr) increased tensile strength and moduli at 100 and 300% of elongation, but also slightly increased water absorption (Oboh *et al.,* 2018). Nanocomposites reinforced with cellulosic nanoparticles can provide adequate synergy for loading bearing and vibration isolation applications (Oboh *et al,* 2018).

The REACH legislation mandates the search for sustainable alternatives to carbon black and silica fillers, as they are non-renewable and hazardous. Nigeria's rice production expansion boosts waste rice husks, but the hydrophilic nature limits their use. Study explores using rice husks as fillers in engineering products, replacing carbon black. Rice husk-treated composites demonstrated superior adhesion and mechanical properties, with tensile strength, compressive strength, and tensile modulus values of 18.5 MPa, 39.72 MPa, and 7.87 MPa, respectively. The rice husk ash-filled natural rubber composites can find application in the development of vibration isolation mounts (Ubi *et al.,* 2022*)*. The results showed the composites had similar mechanical properties to carbon black-filled composites, making them a suitable alternative for various applications such as tyres, engine mounts, bushings, seals, and doormats (Ubi *et al.,* 2023). The developed rubber engine mounts (REMs) and conventional REMs showed low vibration data variation, excellent damping characteristics, and lower transmissibility in the isolation zone (Ubi *et al.,* 2024).

However, Medupin *et al.* (2019) compare the functional properties of a home-grown nanocomposite (NC) and multiflex dynamic response-2 artificial foot (M.DR2). The NC material, with a temperature of 260.01 oC, is 93% more thermally stable than the M.DR2 prosthetic foot, thanks to the addition of MWCNTs.The wear rate results revealed that M. DR2 wears faster than NR/MWCNT-3 by approximately 32%, as shown in Table 8.

Table 8: Wear Rate Results

| Sample | Initial Mass (g) | Final Mass (g) | Density ($g/cm^3$) | Vol. Loss ($cm^3$) | Sliding Dist. (m) | Wear Rate ($cm^3/Nm$) |
|---|---|---|---|---|---|---|
| NR/MWCNT-3 | 3.577 | 3.561 | 0.36 | 0.016 | 4.45 | 0.001977 |
| M. DR2 | 3.107 | 3.089 | 0.31 | 0.018 | 4.01 | 0.002896 |

Moreover, in another study, Medupin *et al.* (2019) revealed thermogravimetric analysis/differential thermogravimetry (TGA/DTG) degradation peaks at 305 °C and 290 °C respectively with temperature range within which the NCs degraded lying between 250 °C and 600 °C. Dynamic mechanical analysis (DMA) revealed that filler incorporation results in higher storage and loss moduli (2000–7500 MPa and 500–1413 MPa, respectively).

## 4.0 FUTURE RESEARCH WORK

Mr. Vice Chancellor, Sir, today's lecture touched on the most active areas of my research activities in the area of Material and Metallurgical Engineering. Apart from the scholarly publications, which are available to the global academic community, my modest contribution to various aspects of life using engineering materials developed has extended to improve life comfort, products like implants, prostheses, and other biomedical instruments, as shown in Figure 19, which are also susceptible to corrosion due to body fluids. The development of biocompatible biocomposites for bone repair and replacement is being explored, utilizing locally made products with the required bioactive, mechanical, and structural properties.

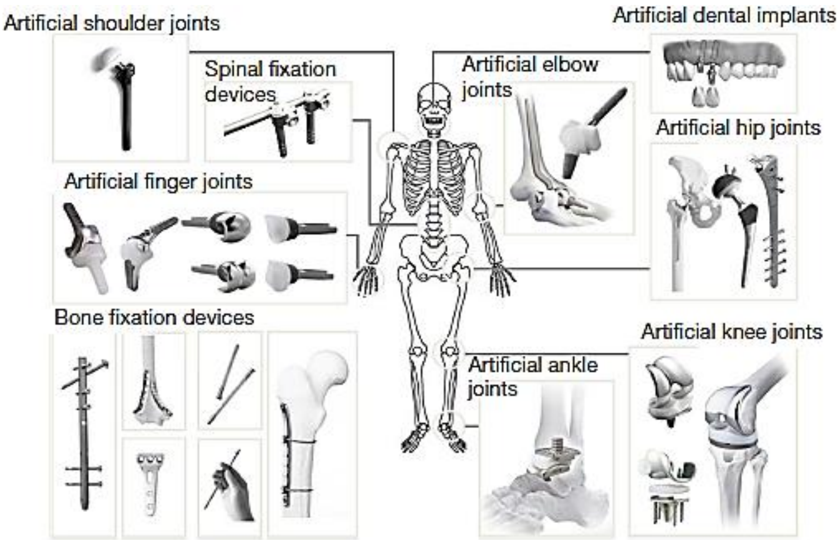



Figure 19: Various metallic Implants and Arear of their Applications

Before clinical investigation, it is very important to study the characteristics of the implant surface, chemical composition, and electrolyte (body fluids) to achieve minimal release of toxic ions and premature failure of the prostheses as indicated in the step shown in Figure 20.

Engineering test e.g Corrosion, mechanical wear, corrosive wear etc → In vitro tests e.g Cytotoxicity, cytogenesis, hemolysis etc → In vivo tests e.g Skin irritation, acute and chronic bone implantation etc

Non-clinical Test | Clinical Test

Figure 20: Steps for checking the Biocompatibility of Joint Prosthesis

To design biocompatible implants, the research study required a suitable consideration of chemical, mechanical, and biological properties. Different aggressive body fluid properties (pH, dissolved oxygen and temperature) and their interaction with the surface caused corrosion and affect the wear properties of the existing load-bearing implant biomaterials (Titanium, Co-Cr, Stainless steel) as shown in Figure 21.

Figure 21: Failure of Metallic Implants due to Corrosion Reaction with Body Fluids

Figure 22 shows the failure with bone due to the stiffness or mismatch of the implant's modulus with host bone modulus that rsulted to premature failure, pain, and required revision of surgery (Ibrahim, Abolarin, Abdulrahman, and Adedipe, 2021).

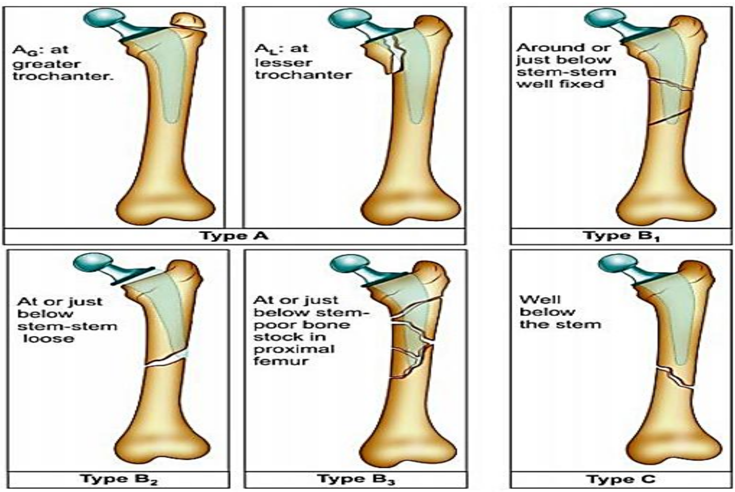



Figure 22: Failure of the Implants with Bone Loss

Recently, traditional prosthetic materials often lack the desired properties to mimic the mechanical behaviours of natural bone, leading to complications and reduced implant longevity. Successful prosthesis application requires chemical stability, mechanical behaviour, and biocompatibility with body fluids and tissues. Advances in biomaterials address implant modulus mismatch and bone-tissue integration. However, research on implant degradation caused by foreign body reactions and electrochemical interaction between the implant and the body fluid using Potentiodynamic Polarisation (PDP) is shown Figure 23.

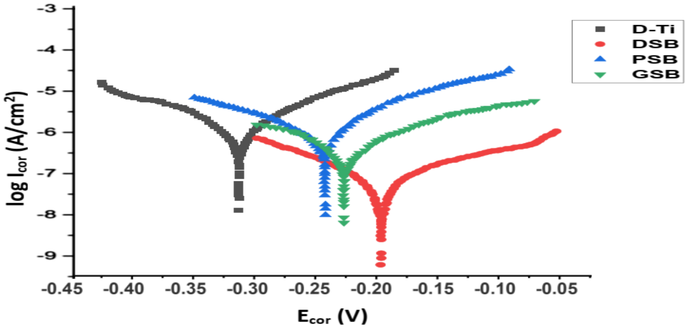



Figure 23: Potentiodynamic Polarisation Plot of D-Ti and Biocomposites

The study explored the use of titanium (Ti), $CaCO_3$, and cow bone-based hydroxyapatite (CB-Ha) shown in Figure 24 as a sustainable alternative to synthetic hydroxyapatite for bio-composite development with Ca/P ratio of 2.1, similar to the quantity found in human bone (2.2).

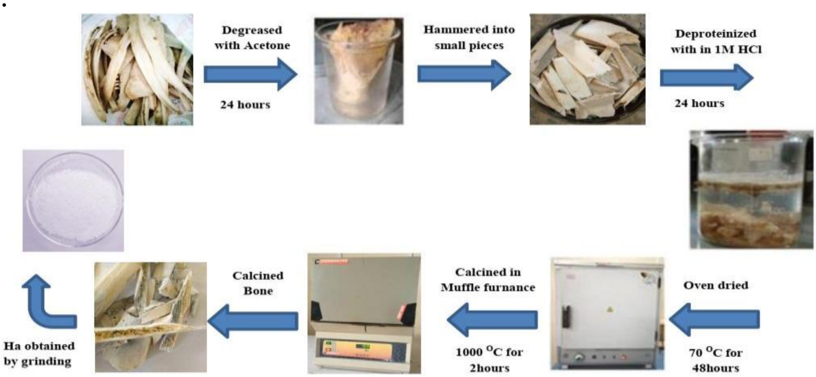



Figure 24: Production Process to Cow Bone-Based Hydroxyapatite Powder

The optimised biomechanical properties of dense and porous structure biocomposites were achieved using optimal compositions of 68.36% Ti, 28.36% CB-Ha, 8.18 $CaCO_3$, and 69.23% Ti, 25.67% (CB-Ha+$CaCO_3$), 1.91% space-holder, respectively. The gradient structure biocomposite (GSB) is the most suitable for mitigating stress shielding due to its compressive strength of 174 MPa and modulus of 29.42 GPa, which is within cortical bone modulus (7-30 GPa). The biocomposites demonstrated excellent bioactive properties, maintaining a physiological pH range and exhibiting low ion leaching in Ringer solution, with the highest ion concentrations for calcium, phosphorus, and titanium ions in the body, indicating excellent bioactive properties (Ibrahim, Abolarin, Abdulrahman, and Adedipe, 2024). The study investigated the biomechanical stability of Ti–Ha–$CaCO_3$ biocomposite hip implants using finite element analysis, highlighting the complexity and time-consuming nature of studying stress distribution and potential failure modes. The Ti–Ha–$CaCO_3$ biocomposite was simulated using SolidWorks, shown in Figure 25, with static loading and ASTM F2996-13 standard.


Figure 25: Assembled femur and stem joint (a) and intramedullary Rod (b), Femoral Implants

The GSB-femur stem model and intramedullary rods for bone fixation model showed maximum von Mises stress below titanium implant yield strength, with DSB being the most suitable model shown in Figure 26.

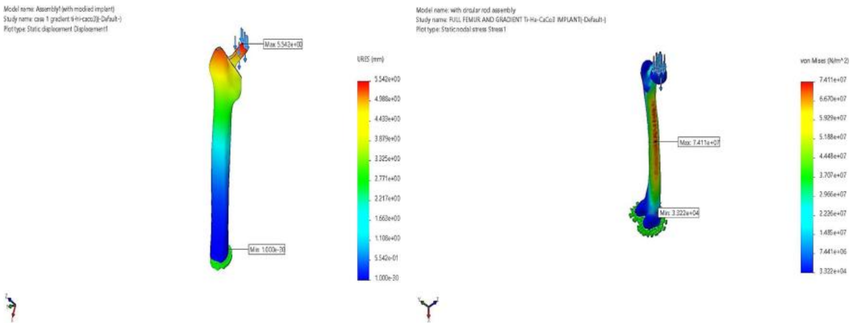


Figure 26: Von-Mises Stress Model for Biocomposite Femur-Stem and Femur-intramedullary rods

Figure 27 shows the comparative assessment of the produced Ti-Ha-CaCO3 biocomposite implants to the existing implants and healthy femur. This revealed that the biocomposite properties are similar to the bone properties, and it is biocompatible.

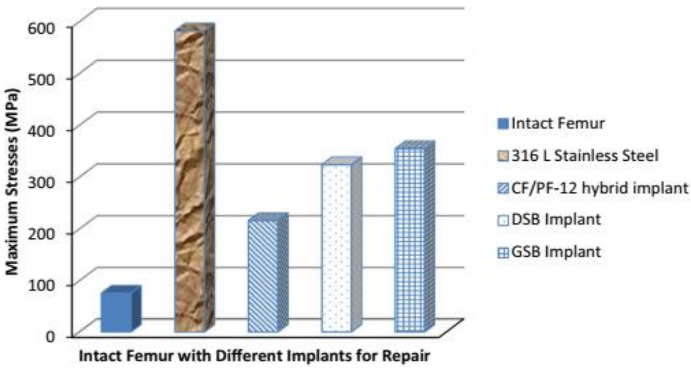



Figure 27: Comparison of intact femur, different implants, and study implant materials

Finally, I look forward to focusing on the following research areas in subsequent years.

i. Fabrications, characterization, and simulation of composite implants for replacement and repair of biomedical applications.

ii. Development of artificial intelligence bioactive devices that can sustain corrosive medium and body fluids using locally available natural materials

By way of improving previous research on the processing of natural ore, minerals, corrosion, and composite development, I will further utilize computational analysis to investigate the effect of corrosion on different composite materials irrespective of their area of applications. I will further work on the development of a computerized ion debris detecting machine in body fluids, and corrosive-wear testing machine to obtain results that will depict a real-life situation of material frictional wear in the corrosive environment.

## 5. CONCLUSION

Mr. Vice-Chancellor, Sir, I have attempted in this lecture to present the potential in utilizing minerals, clays, and concrete as a binder from nature for the production of different engineering materials and accelerated national development. Also, the study focuses on developing coatings, inhibitors, and surface treatments that provide long-term protection against environmental reactions, such as oxidation and moisture-induced corrosion, using nanomaterials. Finally, composite and nanocomposite materials were developed and applied to retard the reaction of the engineering steel with its environmental attack to the natural state. This lecture highlighted the uniqueness of controlling the corrosion of steel structures to reduce the failure of buildings and the destruction of life and property.

## 6. RECOMMENDATIONS

From my research activities and the experiences gathered during the course of these activities, I hereby recommend that:

i. Develop and promote sustainable extraction methods for natural minerals and ores that minimize environmental impact. Research should focus on reducing energy consumption, water usage, and the release of harmful by-products during extraction and processing.

ii. Explore the potential of creating new metal alloys using natural ores that offer enhanced corrosion resistance and longevity. This research should aim to optimize the material properties for use in harsh environments, such as marine or industrial settings.
iii. Develop and standardize a testing rig to evaluate the corrosive-wear of materials under simulated real-world conditions. This should include accelerated aging tests, environmental exposure simulations, and stress testing to better predict material performance over time.
iv. New biocomposite formulations need to be developed to improve the durability and longevity of brake pads, engine mounts, and other automotive components by optimizing the balance between environmental impact and mechanical performance.
v. Conduct long-term studies on the performance and biocompatibility of prostheses for amputees. Focus on materials that offer greater durability, comfort, and reduced risk of complications such as infections or implant rejection.
vi. Investigate self-healing biomaterials for bone repair and replacement to mimic natural bone properties more closely by studying the integration and degradation rates of synthetic materials in vivo to improve their effectiveness and longevity.
vii. Explore biomimicry and nature-inspired designs to develop new materials with enhanced longevity and performance. Nature often provides solutions to material challenges, and applying these principles can lead to breakthroughs in material science.
viii. Encourage collaborative research between material scientists, engineers, and industry experts to address the challenges of material longevity across different applications. Multidisciplinary approaches can provide more innovative and practical solutions that enhance the sustainability and durability of materials.

## 7.0 ACKNOWLEDGMENTS

Distinguished Vice-Chancellor, Deputy Vice-Chancellors, Principal Officers of our great University, esteemed colleagues, guests, beloved students, ladies and gentlemen.

All praises, thanks, and adorations are due to Allah (*Subhanahu Wa Ta'ala*), the Lord of the worlds, who in His infinite mercy has granted me life, health, and the privilege to stand before you today. I am deeply grateful to Allah for His guidance, protection, and countless blessings throughout my journey in life. Without His grace and favour, none of my efforts would have been possible, and to Him alone belongs all the glory and gratitude.

With a heart full of gratitude, I stand here today to acknowledge those whose contributions and support have shaped this journey and made this moment possible. This inaugural lecture is not just a personal milestone; it is a moment to reflect on a journey shaped by the support of many.

I extend my deepest appreciation to the management, staff, and students at the Federal University of Technology, Minna. This institution has been my academic home for many years, providing the environment and support necessary for my research and growth. I am eternally grateful to the management, my senior colleagues, and the entire university community for nurturing my career and allowing me to reach this esteemed rank.

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I remain deeply indebted to the former Vice-Chancellors – Prof. Tukur Saad, Prof. M.S. Audu, Prof. M.A. Akanji, and Prof. Abdullahi Bala. Your collective guidance and leadership have been profoundly instrumental in shaping my professional growth and development. I sincerely appreciate the confidence reposed in me and the steadfast support, encouragement, and resources provided to enable me to excel in my career. Your commitment to fostering a conducive and inspiring

work environment is truly commendable, and I consider it a privilege to be part of such a dedicated and forward-thinking academic community. Thank you for your mentorship, your belief in my abilities, and for the opportunity to work alongside such an exceptional and purpose-driven team. To the former DVCs and Registrars, Prof. T.Z. Adama, Prof. M.A.T. Suleiman, Prof. A.O. Osunde, Prof. S.O.E. Sadiku, Prof O.O Morenikeji, Prof E. Udensi, Prof. A. Iyaka, Mal. M.D. Usman, Mrs. V.N Kolo, and Mr. A.N Kolo, thank you for your support.

Special tribute goes to my teachers and lecturers at various stages of my education. To my earliest teachers, I am grateful for laying the foundation of discipline, knowledge, and values that continue to guide me. To my university lecturers and mentors, I remain indebted to them for their wisdom, encouragement, and scholarly guidance, which have shaped my intellectual growth. Your dedication and passion for education ignited a lifelong curiosity within me and taught me the values of perseverance, critical thinking, and the importance of lifelong learning.

I must take a moment to express my profound gratitude to the former Governor of Kogi State, His Excellency, Alhaji Yahaya Bello. His vision and foresight in establishing the Confluence University of Science and Technology (CUSTECH) in Osara are truly commendable. He did not just build a university; he built a legacy of hope and opportunity for countless young minds. Furthermore, I am deeply indebted to him for the immense trust he placed in me by appointing me as the Vice-Chancellor of CUSTECH. It is an honour that I strive to fulfil every day.

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To the entire Confluence University of Science and Technology (CUSTECH) community, I am profoundly grateful. I want to express my sincere appreciation to the Members of the Council of CUSTECH, led by Emeritus Prof. Olu Obafemi, for their commitment to the growth and stability of our young but promising University. To the Management and staff of CUSTECH, I am deeply grateful for your dedication, teamwork, and sacrifices in laying a solid foundation for academic excellence. And to our dear students, who are the heart of this institution, I commend your determination to make the most of the opportunities provided at CUSTECH. Together, we are building a university that will stand tall among great institutions.

I must also recognize my colleagues across the University system and various research institutes. Your collaboration, constructive criticism, and friendship have provided a stimulating environment for research, teaching, and innovation. To my students, past and present, I extend my gratitude. Your curiosity, resilience, and eagerness to learn have pushed me to constantly improve and give my best.

I must acknowledge all my friends, too numerous to mention, for their unwavering support, encouragement, and goodwill throughout my journey. Your solidarity, prayers, and brotherhood have been a source of strength and motivation. I remain deeply grateful for your sacrifices and the bond we share, which continues to inspire me to give my best in service to humanity and our community.

I owe profound gratitude to my parents for their love, sacrifices, and constant prayers, which laid the foundation for all that I have become today. In a very special way, I celebrate my mother, who stood as the pillar of strength and the major sponsor of my university education. Her

sacrifices and belief in my future remain the cornerstone of my success. The values of discipline, hard work, sacrifices, and integrity instilled in me have continued to guide my steps in life and in service to humanity.

To my incredible wives and children, you are the cornerstone of my life. Your love, patience, and understanding have been my greatest support throughout this demanding journey. This achievement is not mine alone; it is a testament to the sacrifices we have all made as a family, and I am eternally grateful for the love and joy you bring to my life. Your encouragement has been my anchor through long hours of academic pursuit, research engagements, and administrative responsibilities.

I sincerely thank the Chairperson , University Seminar and Colloquium Committee(FUT Minna), and her members who worked tirelessly behind the scenes to make this occasion a success. May God bless you all richly for your efforts.

And finally, to all of you in the audience, thank you for sharing this special day with me. This lecture is as much a testament to your support as it is to my own efforts. I am excited to continue contributing to the academic community and look forward to the future.

Thank you very much, and God bless you all.

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## PROFILE OF THE INAUGURAL LECTURER

Engr. Prof. Abdulrahman Asipita Salawu was born on the 29th of January 1969 into the family of Mall. Salawu Ojirobe Onipe and Hajiya Fatima Momoh Osheiza of Adavi Local Government Area, Kogi State. Prof. Asipita began his academic sojourn in 1977 at the Local School Management Board Primary School in Ikaraworo, Adavi Local Government, Kogi State, and obtained a school leaving certificate in 1983. He had his secondary school education at Community Secondary School (CSS), Ogaminana, Adavi, Kogi State, from 1983 to 1988. He attended Ahmadu Bello University (ABU), Zaria, from 1991 to 1997, where he obtained a Bachelor of Engineering (B. Eng) degree in Metallurgical Engineering. As Providence will have it, he was employed as a Research Metallurgical Engineer at the National Metallurgical Development Centre, Jos, Plateau State, in 1999 before transferring his service to the Federal University of Technology, Yola, as a Lecturer II from 2005 to 2007. Because of his love for academic progression, he obtained a Master of Engineering (M. Eng) from Abubakar Tafawa Balewa University (ATBU), Bauchi, in 2006, after which he joined the service of the Federal University of Technology, Minna, Department of Mechanical Engineering in 2007.

In pursuit of academic excellence, Prof. Asipita obtained his Doctor of Philosophy (PhD) in Engineering from Universiti Teknologi Malaysia (UTM) in 2012. He has won many awards, to mention a few: the Pro-chancellor's Best Graduate Award from the School of Postgraduate Studies, Universiti Teknologi Malaysia, in 2013, and the Award for Excellent Journal Publication, Faculty of Civil Engineering, Universiti Teknologi Malaysia, in 2012. Engr Prof. Asipita has served as Head of Department, Corrosion & Surface Protection Division, National Metallurgical Development Centre, Jos; and Member, Board of Directors (Technical), National Engineering Design Development Institute (NEDDI), Nnewi, Anambra State. At the Federal University of Technology, Minna, he has served as Head of Department, Metallurgical Engineering; Member of the Governing Council; Sub-Dean, School of Engineering and Engineering Technology; and Chairman of many committees, among others. Engr. Prof. Abdulrahman firmly holds the principles of Professional Ethics. As a core member of the NSE who has always upheld the values and ideals of the Society, he has served the NSE in several capacities both at the National, Division, and Branch levels, amongst which include Chairman, Nigerian Society of Engineers, Yola Branch (February to August 2007); and Chairman, Nigerian Society of Engineers, Minna Branch (2009-2010). He is the immediate past National Chairman of the Nigerian Institution of Metallurgical, Mining and Materials Engineering (NIMMME or 3M). Prof. Asipita had many research publications to his credit. As a lecturer, he taught many undergraduate and Postgraduate courses, supervised many students, and researched extensively. Prof. Asipita, as he is fondly called, rose quickly through the ranks to the Chair of Professor of Metallurgical Engineering on the 1st of October 2019 as a testament to his profile and scholarly peer-reviewed publications in National and reputable international journals.

As an ardent scholar, He has published and presented several technical papers at local and international fora. Some of his most cited papers are:

1. Green Bambusa Arundinacea leaves extract as a sustainable corrosion inhibitor in steel reinforced concrete.
2. Vegetable oil-based lubricants: Challenges and prospects.
3. Biomechanical and physical properties selection of Ti-Ha-$CaCO_3$ biocomposite prostheses for replacement of bone atrophy.
4. Corrosion inhibitors for steel reinforcement in concrete: A review.
5. Microstructural and corrosion behaviours of dissimilar friction stir welded aluminium alloys.

He is an external examiner to many national and some international universities and has two patents to his credit (NG/P/2023/379 and NG/PT/2024/11049). He is a COREN Examiner and has served on several COREN and NUC accreditation teams.

A COREN certified Engineer, he is a Fellow of the following professional bodies:

a. The Nigerian Society of Engineers (NSE).

b. Nigerian Institution of Metallurgical, Mining & Materials Engineers (NIMMME)
c. Nigerian Metallurgical Society (NMS)

In December 2023, Engr. Prof. Asipita was appointed Vice-Chancellor of the Confluence University of Science and Technology (CUSTECH), Osara, Kogi State. He inherited 38 programmes across six (6) Faculties. In less than one year in office, he created three (3) additional Faculties/Colleges – Agriculture, Medical Sciences, and Law. He established fourteen (14) new programmes, and these are Agricultural Science, Agricultural Engineering, Marine Engineering, Materials and Metallurgical Engineering, Mechatronics Engineering, Petroleum and Gas Engineering, Law, Medicine and Surgery, Human Anatomy, Medical Laboratory Science, Nursing Science, Physiology, Physiotherapy, and Radiography.

Prof. Asipita is a results-oriented personality who has distinguished himself among his peers through strong character, integrity, charisma, and uncommon leadership skills. He is administratively reliable, morally disciplined, and academically sagacious.

Since he took the mantle of leadership of CUSTECH, the University has witnessed many developmental projects, and principally among these are the groundbreaking ceremonies for the establishment of Barefoot Renewable Energy College, supervised by the Energy Commission of Nigeria (ECN), and the Livestock Service Centre, which is coordinated by the Livestock Productivity and Resilience Support (L-PRES). Within two years of assuming office as the Vice-Chancellor of CUSTECH, he has navigated challenges with grace and determination, implementing innovative strategies that have revitalized the University. His visionary approach and commitment to excellence have transformed the University into one of the fastest-growing universities in Nigeria, fostering an environment of innovation, collaboration, and academic growth. The University has witnessed significant advancements in research, student engagement, and community outreach, setting a new standard for the institution.

Despite his busy schedule as Vice-Chancellor, Prof. Asipita remains active in research and development and has many publications to his credit. His flair for research and publication birthed three journals by CUSTECH – The Confluence University Journal of Science and Technology (CUJosTech), The CUSTECH International Journal of Education (CUSTECHIJOE), and The CUSTECH Journal of Science, Technology and Innovation (CUJOSTI).

Prof. Asipita's commitment to serving God and humanity is highly commendable. His resumption as the Vice-Chancellor of CUSTECH kick-started the observance of Friday Muslim congregational prayers at CUSTECH. Since he assumed office as the Vice-Chancellor, confirmation of appointments of deserving staff has been made. Similarly, staff who are due and qualified for promotion have been promoted.

To alleviate the hardships university staff face in transporting themselves to Osara, Engr Prof. Abdulrahman approved and dedicated one university bus to convey staff from Okene to Osara (and vice versa) daily. In the illustrious tapestry of academia, there shines a beacon of brilliance, a leader whose profound dedication and unwavering commitment to excellence have left an indelible mark on the landscape of academia. Prof. Asipita, an esteemed professor of Metallurgical and Materials Engineering, is happily married with children.

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