OBAFEMI AWOLOWO UNIVERSITY, NIGERIA

Inaugural Lecture Series 80

MATERIALS, ENERGY AND THE ENVIRONMENT

by Adeniyi A. Afonja

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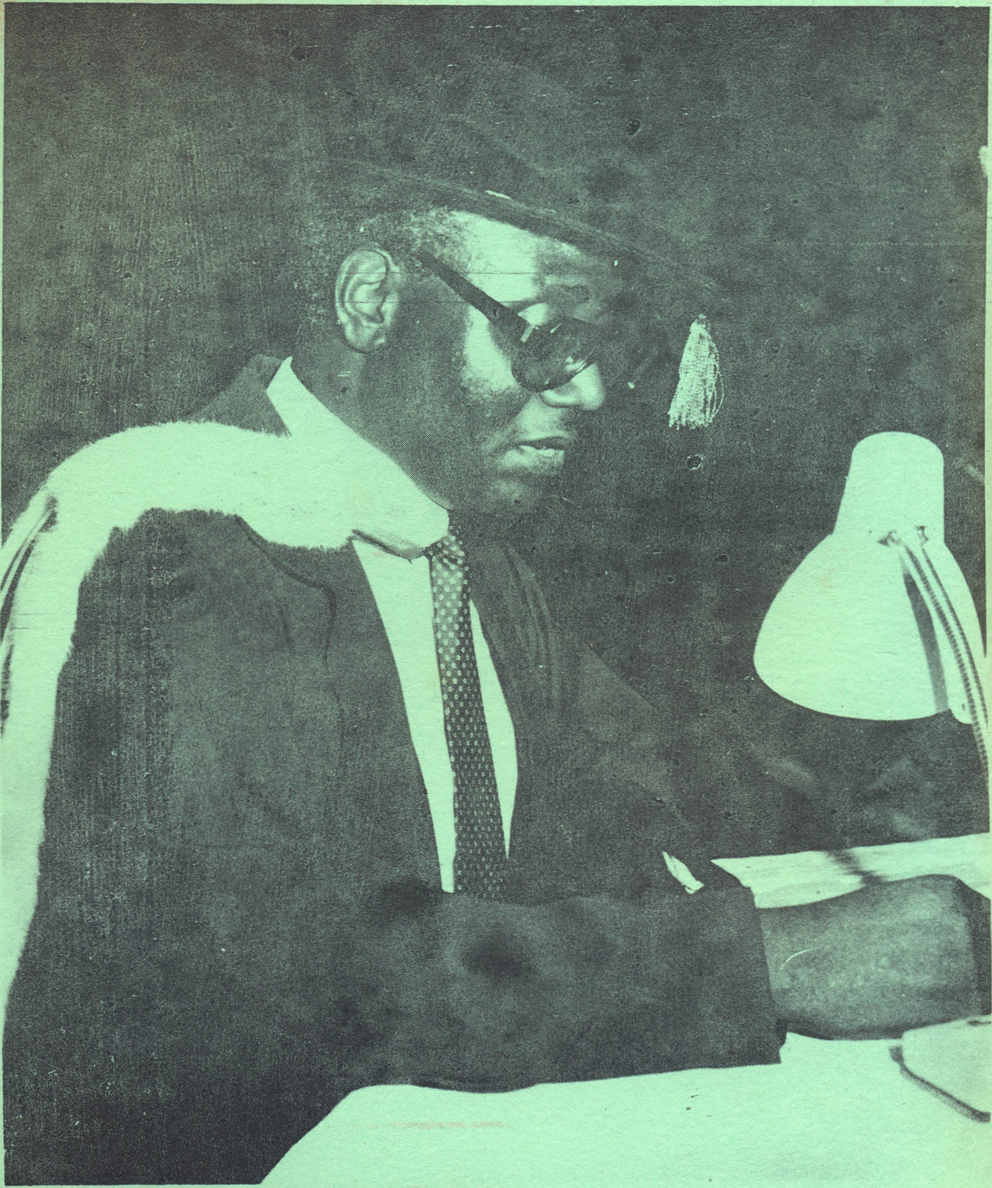

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1. INTRODUCTION

Materials, energy and the environment constitute a major resource triangle which forms the physical base of any economy and, to a large extent, determines the level of social and technological development of a nation. In order to appreciate the prime role of materials, we only need to reflect briefly on what life would be like without wood, metals, clay, sand, glass, rubber and plastics. Energy is one of the most critical inputs in materials production. About 40 percent of the world's total energy consumption is expended in producing and processing materials. It is not surprising therefore that fluctuations in the world energy scene greatly affect the economics and availability of materials. On the other hand, the relatively slow pace of development of heat and corrosion resistant materials is a major constraint on the development and utilization of alternative sources of energy. The environment is both the source and the sink for energy and materials and development in either field usually has profound environmental implications. So far, there has been a tendency all over the world to treat the problems of materials, energy and the environment in isolation, but recent experience has shown that the three factors interrelate and interact in a very complex manner and a systems approach is imperative for any meaningful research involving any of these important resources. In this lecture, the materials – energy – environment interface is examined critically with particular emphasis on solid materials which are of primary importance to industrial development. The current development in materials science and engineering will be examined and the contribution emanating from teaching and research activities at the University of Ife, outlined.

2. MATERIALS AND MANKIND

Perhaps the best way to appreciate the indispensability of materials to mankind is to review a few hours in the life of an average modern man. He wakes up in the morning from a bed made of wood, steel and polymer, cleans his teeth with a brush made from polypropylene handle and nylon bristles, he takes his bath in an enamel plated steel bath. he dresses up wearing a nylon shirt, a terylene suit, leather shoes, and a quartz watch. He takes his tea from a ceramic tea cup, drawn from an 18/8 stainless steel-jug. He drives to work in a car which comprises iron, steel, copper, aluminium, glass, plastics, rubber, etc, listening to the news on his radio which is made of silicon chips, metallic and ceramic resistors, etc. This is only the beginning of a day during which hundreds of materials may be used. Indeed man is always in contact with at least a major material at any moment in his life cycle. Clearly, materials play a very critical role in the existence and development of mankind.

Modern technology depends heavily on materials such as wood, metals, glass, plastics, rubber and ceramic products. These engineering materials through design, manufacture, assembly and quality assurance, become products – structures, machines, devices, tools, utensils, clothing, weapons, ornaments and innumerable products by which we live.

Indeed, the pattern of consumption of engineering materials has become a strong indicator of the level of development of modern civilization. For example, the level of steel consumption is a fairly reliable measure of the level of industrial development of a nation. A level of 40kg per capita is considered the absolute minimum for growth in industrial development. Figures for industrialized countries range from 400 to 650 kg. compared with 30kg for Nigeria and even lower for other less developed countries. A civilization is both developed and limited by the materials at its disposal and this has been evident from time immemorial.

3. HISTORICAL PERSPECTIVES

Historians often label civilizations by the materials they have used: the Stone Age, the Bronze Age and the Iron Age.

However, this method of dating is quite recent and the origin of materials is traceable to about 20 billion years ago when the earth was created.

3.1 History of Materials

From time immemorial, man has learnt to use materials found around him: bone, hide, fibre, wood, stone and shells were somehow fashioned into clothing, shelter, utensils, weapons and tools. Archeological history records many ways in which materials deeply influenced social change and thereby caused society to depend even further on materials. The Stone Age man some 10,000 years ago was quite proficient in flaking flint into knives, hand axes, spearheads by hammering with selected stones. There is in fact evidence that this early man was already familiar with a fundamental and powerful concept in materials engineering – the materials given by nature can be deliberately improved by treatment. He knew how to improve the plasticity of clay by optimising the water content. He was able to improve the strength and rigidity of this material by heating and he sometimes heat treated flint to make it more chippable into the desired shapes.

There is ample evidence that man was already smelting metals by 650 B.C. In fact, the Biblical Cain was described as a worker of brass. Man had learnt to make fires hot enough to melt metals in earthenware containers, which the Romans called 'crucibuli' and which we now call 'crucibles'. He discovered that the molten metal could be poured into the cavity made by placing together two halves of a hollowed-out clay or stone mould; the metal filled the cavity and, when solid, it was found to have taken the shape of the cavity, the very humble beginnings of a very important modern metallurgical process called 'metal casting'. Probably the first metal to be smelted was copper extracted from malachite in Yugoslavia. Man soon started to experiment by blending metals to obtain alloys which were sometimes stronger, harder and tougher than the metals of which they were composed. Probably the earliest alloy made in this way was a bronze consisting of copper and 10 percent tin. There is evidence that he understood that the hardness of the alloy was a function of the level of tin content, hence he was able to produce a variety of grades to suit different applications. About this time, man was also perfecting the art of glazing pottery.

In India, lead, gold and silver were being extracted some 4,000 years ago, presumably inspired by the desire for ornamentation, jewelry and prestigious burials. Iron was also being extracted and processed by the Romans. The art of war and hunting also provided a stimulant to the progress of metals development. Heat treated forgings of swords and spears with amazingly good penetration properties were being made from the Bronze Age. For many thousands of years after, man appeared to be satisfied with the available range of materials and development slowed down. The dozen or so metals in general use persisted until only about a century ago although about twice as many were known by then. One notable exception was the art of electroplating copper objects with gold which was being practiced in parts of Latin America and India as far back as 100 A.D.

Perhaps one of the most important historical developments directly attributable to materials availability was the art of writing and printing. As early as 3,500 B.C. the Sumerians of the Tigris-Euphrates Valley had developed clay writing tablets and adopted sharp rigid stili for inscription. About the same time, the Egyptians had adopted flexible fibres in the form of papyrus reeds, native to the Nile region, which could be matted into a writing surface with brushes and coloured fluids as markers.[1] However, one of the most outstanding developments came some five thousand years later, in the 15th century when the Koreans invented the bronze cast movable type for printing. This multiplied by an astounding order of magnitude the amount of information that could be documented and stored.

The Iron Age commenced around 1500 B.C. when it started to replace copper and bronze as materials of construction. The relative abundance of this material coupled with the relative ease with which it could be extracted made it to rise rapidly to the status of the 'democratic metal'. Products of iron such as implements, utensils and weaponry were no longer the exclusive preserve of the elite as was the case with copper and bronze products. The impact of this metal on society was phenomenal. It helped to proliferate the use of craft and agricultural tools and the design and construction of simple machines. Subsequent efforts were devoted to the construction of larger and more efficient furnaces to produce metal in great quantity. This provided the impetus for the industrial revolution and the development of the so many products which we now take for granted today. The materials – mankind interrelationship and interdependence have been evolving over some 50 thousand years and now manifest themselves in virtually every aspect of human life and development.

The current period should be appropriately called the Steel Age since approximately 10 times as much steel is used in the world today as all other metals combined. The development really gathered momentum towards the end of the nineteenth century when Henry Bessemer developed a process for rapidly converting large quantities of iron into steel. Several other processes have since been developed and the production of a large variety of grades, about 2,000 to date, perfected. Steel has retained its dominant role as the prime material of construction but this position is now being eroded by the development of other materials such as polymers, aluminium alloys, ceramics, etc. Indeed, it would be more appropriate to describe this age as the boundary between the Steel Age and the New Materials Age. The discovery of the transistor in 1948 launched a new and vital phase in the history of materials. The chain reaction has been so phenomenal that it is difficult to imagine that it all started less than forty years ago. Other areas of recent developments include medicine, dentistry, aerospace and weaponry.

3.2 Our Materials Heritage

Fela Anikulapo Kuti once sang and I quote, "You will never know where you are going unless you know where you are coming from." It is important therefore that we should recognise our humble background in materials technology. There is ample historical and archaeological evidence that Africa has a very long and rich materials culture. It is an established fact that the earliest hominids who were ancestral to man evolved in the eastern part of Africa. Fossil evidence for this has been found in Ethiopia, Kenya, Tanzania and the Transvaal.[2] It is not surprising therefore that some of the earliest types of tools made from stone and used by the earliest accepted type of human, known as Homo erectus, were found in these parts. They consisted of crude cutting and chopping tools known as Oldwan-type tools and have been dated to the time range of 1½ to ½ million years ago.[3] Over the years, better methods of manufacture of tools evolved which resulted in products of fine craftsmanship called Acheulian tools. (Figure 1). Some of these have been found in Jos Plateau in the tin-bearing gravels and the NOK Valley, some of them having a radiocarbon date of over 40,000 years.[4]

The earliest modern man, Homo Sapiens, has been shown to be present in East Africa by 40,000 B.C. By this time, the tools had become much more sophisticated, with complex designs and geometric shapes. Some interesting samples of these tools have been found in many parts of Nigeria including Jos Plateau,[5] Asejire Dam[6] and Odo Ogun,[7] dated about 18,000 years (Figure 2). With the advent of the late Stone Age some 15,000 years ago came the invention of the bow and arrow which had tiny stone tips. This event represented a considerable advance in materials technology because, for the first time, man demonstrated the capability

Figure 1: Acheulian Tools that were being made in Africa probably more than a million years ago.

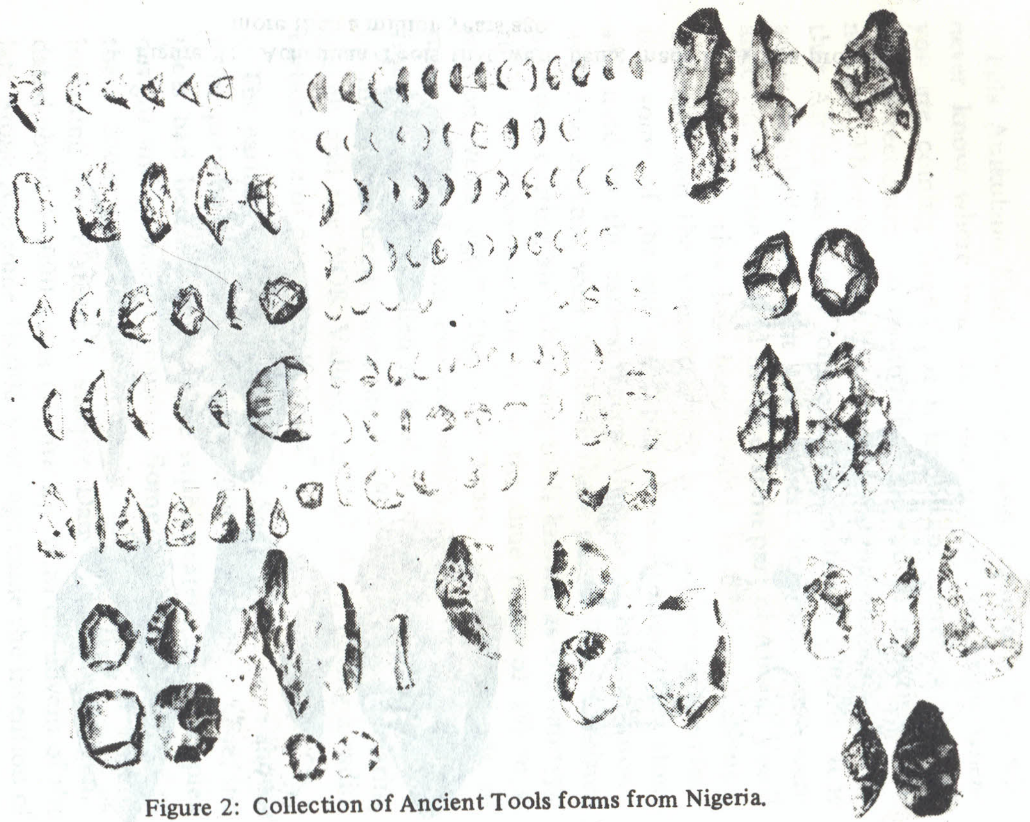

Figure 2: Collection of Ancient Tools forms from Nigeria.

to combine different materials to form composite tools thereby laying the humble foundations of the modern composite materials technology. Some microliths (remnants of bows and arrows) have been found in Wana and Rop in Plateau State,[8] [9] and Old Oyo.[10]

There is ample archaeological evidence that iron was being smelted in the Northern and Central parts of Nigeria by the later part of the first millenium B.C. This development considerably enhanced the capability to clear forests for agriculture, dig wells for water and produce beautiful and complex works of art in terracotta designated as belonging to the Nok Culture (Figure 3–5). It is not clear how widespread the technology was, but excavations in Taruga about 55km Southeast of Abuja led to the discovery of thirteen iron-smelting furnaces and iron artifacts dated to around the fourth century B.C., the oldest so far discovered in West Africa. The absence of alluvial admixure showed that the Nok Culture people employed a fully evolved iron technology. Other excavations made in Bussa area (Borgu) in 1966 to 1968 and 1975 showed that there also were agricultural communities using iron tools before the end of the first millenium B.C. About 200 objects made of iron were discovered. The thirteen furnaces excavated were all low shaft furnaces consisting of pits dug into the ground and containing slag and charcoal. Some tuyeres were found, though not in position. Iron was smelted presumably from limonite and haematite pebbles, magnetic sand, ferruginous sandstone and ferricrete, all of which are abundant in many parts of Nigeria.

It is not clear how Nigeria came to acquire iron technology. Many theories have been propounded but most are incompatible with the Taruga discoveries. A feasible theory suggests that the technology came from Egypt which was known to be smelting iron before 600 B.C. A more favoured theory suggests that it came from Carthage, founded towards the end of the ninth century B.C. by the Phoenicians who

Figure 3: Terracotta heads of the Nok Culture

Figure 4: Terracotta heads of the Nok Culture

Figure 5: Excavations of Terracotta heads and carvings from Owo Area

had migrated from areas where iron was being widely used earlier than it was in Egypt. It is believed that the transfer of technology was through the Garamantes, a powerful tribe in North Africa which interacted with both the Phoenicians and the West Africans.

One interesting and curious aspect of the development of metallurgy in Nigeria is the fact that the Iron Age preceeded the bronze age, unlike in other parts of the world. The first bronze castings discovered in Nigeria were at Igbo-Ukwu, about 40km Southeast of Onitsha, placed by radiocarbon dating at the ninth to the tenth centuries A.D. (Figures 6—8). Most of them had beautiful and complex designs, some obviously produced by the 'lost wax' process, an important process in modern metal casting technology. Most of the castings were made of alloys of copper and tin and some lead while those produced by working were made of almost pure copper, indicating that the ancient craftmen were aware of some fundamental principles of metallurgy: the fact that leaded bronze is less ductile than copper and more suitable for casting while copper can be more easily twisted and engraved than bronze. One reason which has been adduced for the relatively late introduction of bronze into Nigeria is the fact that copper, the main constituent is not known to exist in Nigeria. Other important excavations of bronze figures have been made in Jebba. It is believed that bronze technology was much more widespread in the country and further archaeological excavations may reveal a much richer tradition.

The excavations made at Ile-Ife about the turn of the century were even more interesting. Apart from a wide range of terracotta and bronze masks, a number of brass artifacts mostly heads and masks have been preserved. (Figures 9-12). It is not clear how the copper or the zinc was obtained but it is believed that the art of brass casting was introduced to the region by Obalufon, the third Ooni of Ife. Many of the masks were made of almost pure copper, the most famous being the Obalufon mask, and Lafogido, thought to represent the Ooni in his regalia.[11] The Ife structures had unique, attractive and naturalistic style. There is also evidence that glass beads for jewelry were being produced in Ife and its environs, although it is not clear whether the beads were locally produced or imported. The striking similarities between these artifacts, and those found in Benin and the fact that, historically, Benin derived from Ife have given rise to the widely accepted theory that the Benin brass culture originated from Ile-Ife (Figures 13 & 14). However, the Benin culture is more famous worldwide apparently because of its proximity to a sea port and the much wider variety of artifacts that have been preserved and are available in museums in many parts of the world. It is disheartening to note that most of the traditional bronze and brass culture of Nigeria has become virtually extint.

4. MATERIALS, AFRICA AND GEOPOLITICS

By accident or design, nature placed the bulk of the most strategic materials in the developing world while most of the consumers are in the developed world giving credence to the age long Yoruba adage translated literally as: 'those who have heads have no cap'. Some of the world's best iron ores are located in Brazil, Liberia and Guinea. Zaire is the world's largest producer of germanium and cobalt; Zimbabwe produces 65% of the wold's output of corundum and holds about a quarter of the world's reserves of lithium; Zambia is one of the world's most important sources of copper; Nigeria has a significant proportion of the world reserves of tin, columbite and tantalum; Namibia is a major producer of arsenic, vanadium, lead, zinc, lithium and uranium; South Africa is the world's largest producer of antimony, gold, platinum, rubidium, chromium, vanadium and gem diamond, second only to the U.S.S.R. in the production of manganese and palladium, and third in the production of asbestos. Table 1 shows the reserves of important materials located in developing countries as a proportion of world reserves.

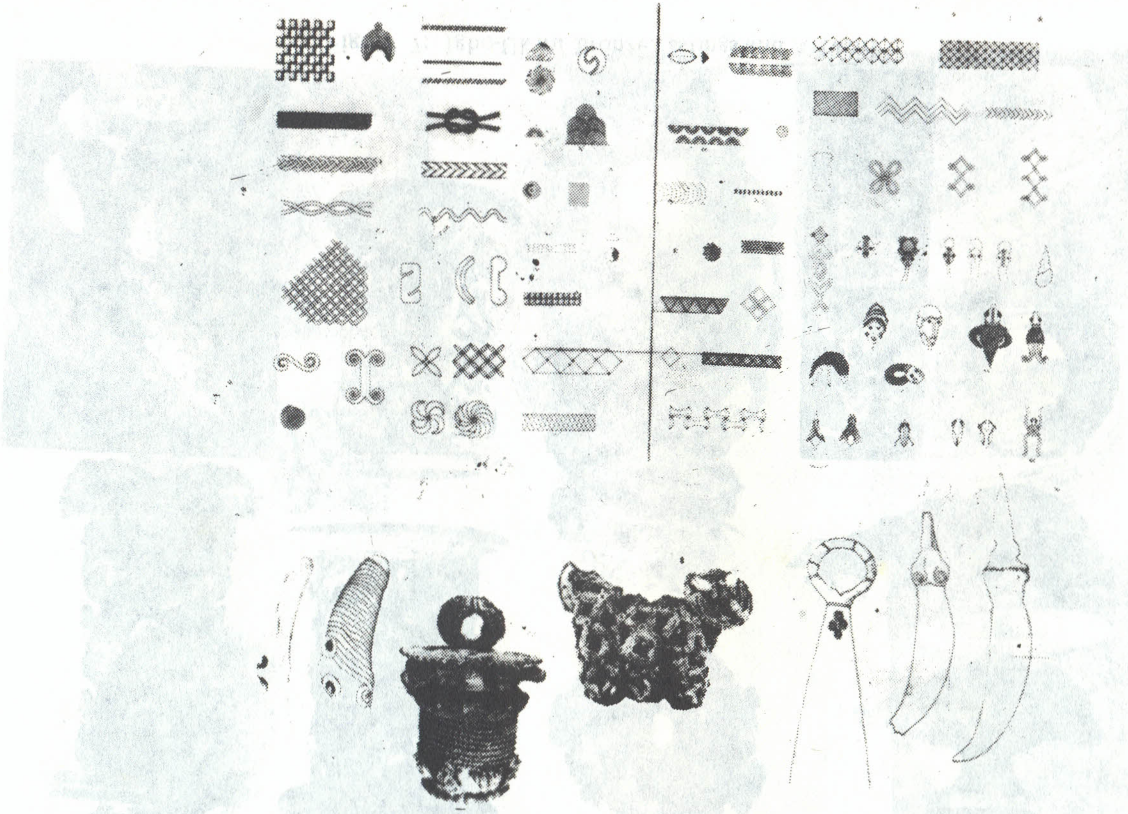

Figure 6: Artwork and Ornamental designs of the Igbo-Ukwu Culture

Figure 7: Igbo-Ukwu Bronze castings and Artwork

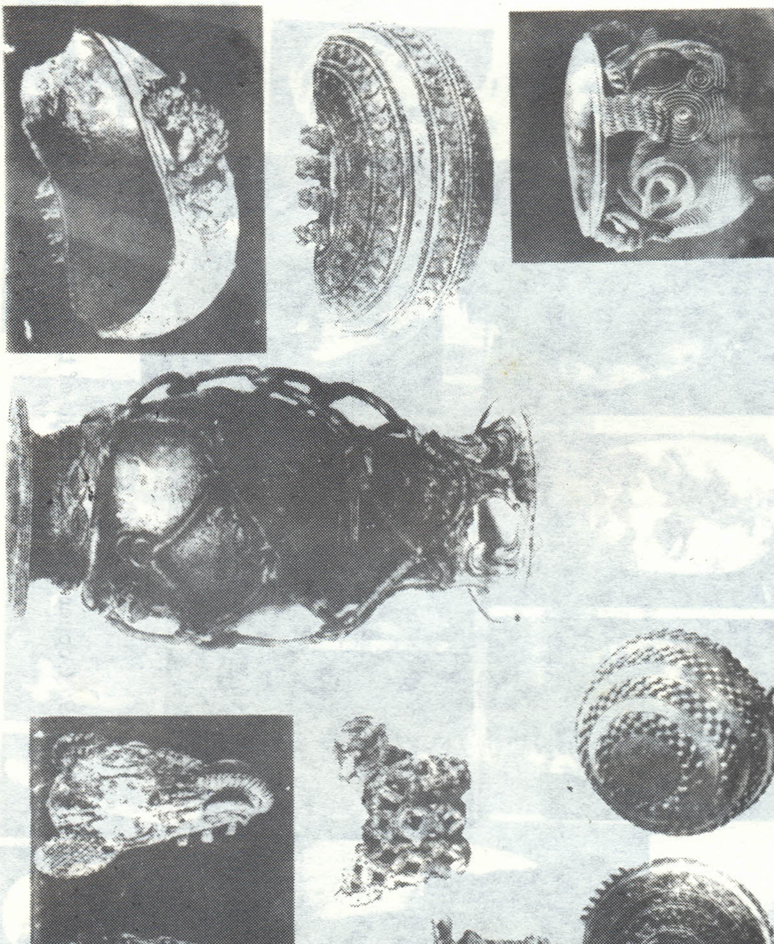

Figure 8: Igbo-Ukwu Bronze castings and artwork

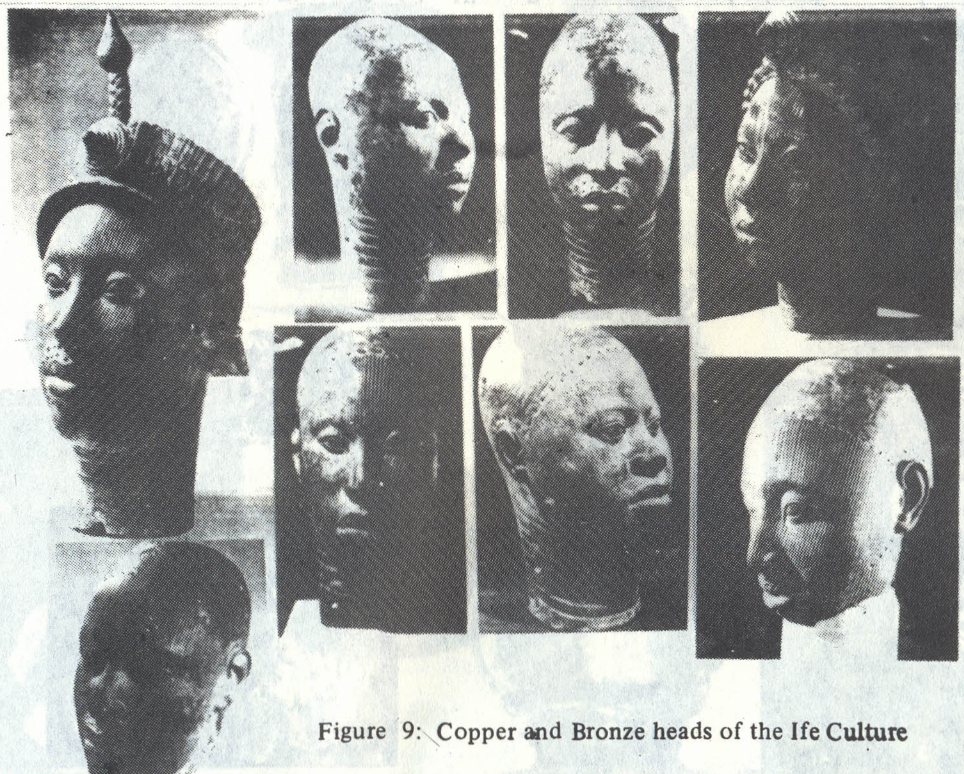

Figure 9: Copper and Bronze heads of the Ife Culture

Figure 10: Terracotta artwork and carvings of the Ife Culture

Figure 11: Copper, Bronze and Terracotta products of the Ife Culture

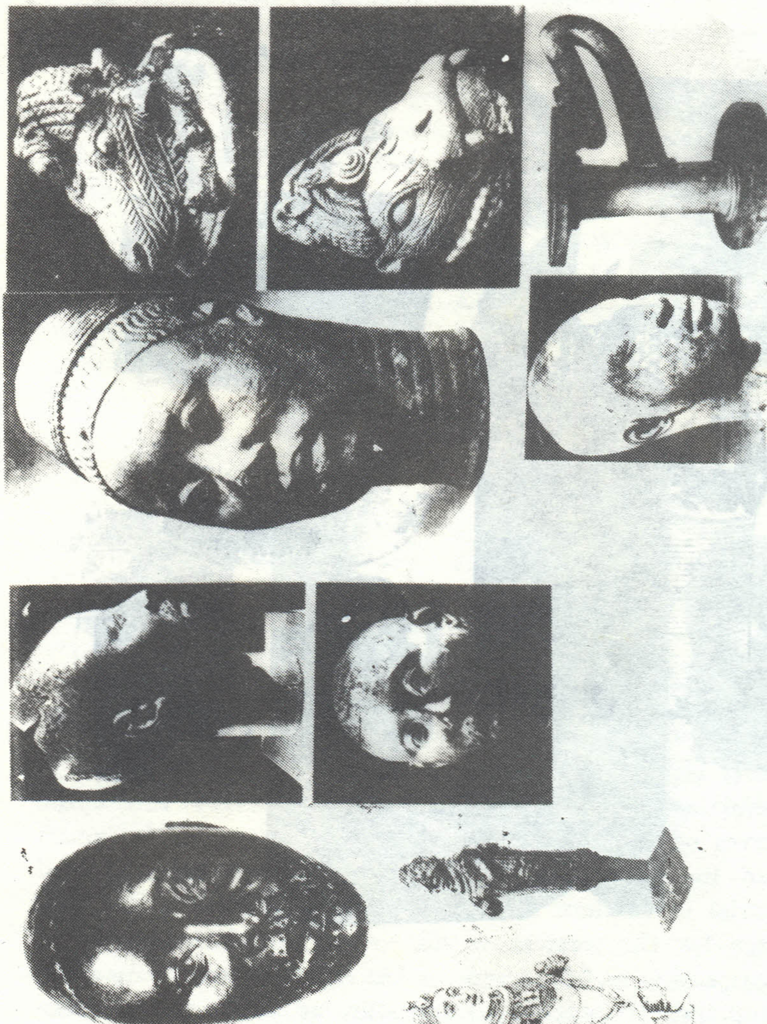

Figure 12: Terracotta and Copper forms from Ife Area

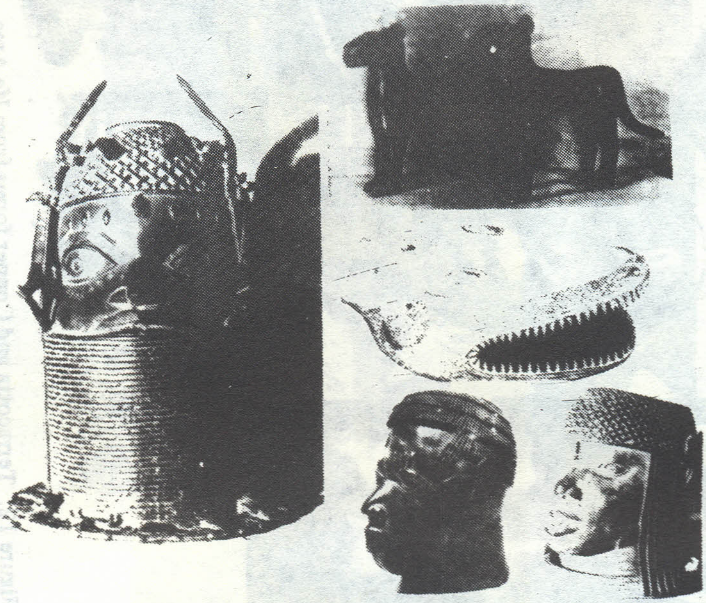

Figure 13: Brass Artwork of the Benin Culture

Figure 14: Brass and Ivory heads and structures of the Benin Culture

Table 1:
Estimated Percentage World Distribution of Important Material Ores

Material Ores	*South America*	*Africa*	*Middle East & Asia*	*Western World*	*Socialist World*
Iron	6.8	4.1	7.5	64.0	36
Copper	16.6	20.7	2.1	81.6	18.4
Aluminium	19.3	5.8	1.3	79.9	20.1
Chromium	0.4	55.2	0.8	59.9	40.1
Cobalt	–	81.4	–	100	(*)
Beryl	39.2	33.5	–	85.0	15.0
Antimony	14.8	21.4	26.8	58.7	41.3
Gold	1.8	60.8	0.4	74.6	25.4
Manganese	9.6	46.1	6.9	62.6	37.4
Platinum	1.9	85.6	–	85.6	13.0
Vanadium	–	52.6	(*)	100.0	(*)
Tin	–	10.2	14.7	74.3	25.7
Columbium–Tantalum	18.5	50.1	(*)	100.0	(*)
Tungsten	6.5	1.0	54.3	36.0	64.0
Lead	8.2	7.4	5.9	73.7	26.3
Uranium	–	20.0	(6)	100.0	(*)
Diamond	4.2	92.1	–	96.3	3.7
Titanium	–	39	33	–	(*)

* *data not available*

It is clear from this table that the developing world in general and Africa in particular holds very substantial reserves of strategic material ores. For example, chromium is an indispensable constituent of stainless steel, a vital material in modern technology and Zimbabwe is the only source for the western world. Also, the United States of America obtains 50 percent of her cobalt requirements from Zaire, and 66 percent of ferrochrome, 44% of ferromanganese, 89% of chrome ore, 52% of antimony, 37% of vanadium, 92% of platinum, 85% of asbestos and 98% of manganese are all from South Africa. It is inevitable from the foregoing that mineral raw material supply is a very potent factor in geopolitics. It is important also that the sources of vital minerals must be kept open at all costs. If for example South Africa and the Soviet Union were to cut off the supply of manganese or chromium (between them they hold 95 percent of world reserves), much of the modern technological world would grind to a halt because steel which constitutes about 90 percent of the world total utilization of metals cannot be produced. It is clear therefore why the political dynamics of Southern Africa is of vital interest to the Western world. Although Southern Africa is already an established repository of much and in some cases virtually all of the known deposits of very important materials, much of the continent is still unexplored and the indications are that her mineral wealth is considerably more than established so far.

5. MATERIALS IN THE SERVICE OF TECHNOLOGY

Archaeological history presented earlier has shown many ways in which materials deeply influenced social change and thereby caused society to depend even more on materials. The trend has persisted till today and material repercussions shape our daily lives and the destinies of nations. In fact, the pattern of material consumption is a strong indicator of the level of social and technological development of a society. A few examples will illustrate the inextricable interrelationship between man, materials and technology.

5.1 Materials in Transportation

Transportation is one of the areas of social life in which technological and materials development has made a significant impact on the greatest number of people. The development of the railways towards the end of the last century would have been impossible without the appropriate materials. The steam engine had to be constructed from materials which were resistant to both steam (a highly corrosive medium) and temperature, while the wheels and tracks were made from wear resistant steel. The automobile was a logical development from the horse-drawn and steam carriages of the nineteenth century. Again, its development and evolution over the years have posed a very formidable challenge to the materials industry. Materials have had to be developed for engine components, chassis, ancillary equipment, tyres, cab, brake system, etc.

Indeed, the modern motor car provides a good illustration of how a large number of different materials can be integrated to achieve this milestone in modern technology. The body and fenders are made of mild steel; the crankshaft, gears, connecting rods, valves, camshaft of various grades of steel; the pistons may be of gravity-diecast aluminium alloy, with cast iron piston rings. The cylinder block may be of cast iron or aluminium, the cylinder head is of aluminium or magnesium alloy, the gear selector fork is of a copper alloy, or aluminium bronze. Bearings may be of tin alloys, leaded bronze, phosphor bronze or aluminium alloy, the door handles of zinc alloy electroplated with copper, nickel and chromium, the radiator tank made from brass, the body trim from high purity aluminium, stainless steel or rubber, the windscreen from glass, the spark plugs from nickel alloy containing manganese, chromium or silicon and ceramics, the contact breaker points from tungsten, the seats and dashboard from polymers, to name a few.

Other developments which complemented those in the field of automotive materials technology included advances in machine tool technology, metal-working and joining processes, materials protection, machine design etc. The pace of development of ships has been controlled by man's ability to develop materials capable of taking high stresses in highly corrosive media. However, few, if any developments in engineering have made a greater impact on society than mechanical flights. Although the Chinese seem to have discovered many of the fundamental concepts of aviation between 600 and 2,400 years ago, the first successful man-carrying flights were made just 80 years ago. Since then progress has been spectacular and its consequences have altered the course of history.

Materials for the construction of airplanes have evolved from wood and wire to tubular steel and light alloy strip. Progress in modern aerospace technology depends heavily on the development of appropriate materials including strong, light alloys, superalloys capable of withstanding high combined stresses and temperatures, material composites, ceramics, and polymers. The aircraft built by the Wright Brothers in 1903–05 had an unladen weight of only 275kg, the engine alone accounting for 30 percent of the weight, covered a maximum distance of only 15km, had a maximum flight duration of only 38 minutes, and carried only one passenger. By contrast, a Boeing 747 built in 1983 had an unladen weight of 380 tonnes (including fuel), the engine contributing only 5 percent of the weight; it can fly non-stop for 13 hours, covering a maximum distance of 11,000km, carrying 550 passengers and tonnes of luggage. This development was made possible by the invention of the jet engine by F. Whittle of Britain in 1932 and the development of strong, lightweight and temperature resistant materials. Superalloys capable of withstanding temperatures up to 2,000°K and titanium alloys which have up to 40 percent strength to weight advantage over steel had to be developed to achieve the high power to weight ratio required for such outstanding performance. Improvements in body structure have been due mainly to the development of high strength aluminium alloys, metal – non-metal composites, rubber and plastics. An even faster aircraft capable of supersonic flying at 1.5 to 2 times the speed of sound has been in commercial operation for ten years. Recently, the US President announced that a hypersonic aircraft capable of flying at 21 times the speed of sound thus reducing the flight from the U.S.A. to Japan from 15 to 2 hours will be in commercial operation within the next decade. This feat can only be achieved if super strong, lightweight and heat resistant materials are developed.

5.2 Materials in Electronics

The phenomenal development of the electronics industry in the last thirty years or so is a direct result of progress in materials technology. The discovery of the transistor in 1948 was a milestone in the history of technology. Ultra-high purity single crystals of silicon and germanium were required for transistors and commercial production of both metals was a result of years of intensive research on metal purification by zone refining and single crystal technology. It became possible to prepare metals which are spectroscopically pure with impurity level as low as 10^{-9} ppm. The principle of zone refining was extended to zone levelling, a process by which the residual impurities in the metals are levelled to obtain uniform distribution, a primary requirement for semiconductor materials.[1 2] The development of the thin-neck technique made it possible to grow dislocation-free single crystals under carefully controlled conditions. It has not been possible to commercialize this process due mainly to the difficulty of keeping the material dislocation-free throughout the processing steps during device fabrications.

Considerable research effort has been expanded over many years therefore to minimise the dislocations and determine their effects such as interference with dopant diffusion during device fabrication, the generation of breakdown sites, the heterogeneous nucleation of dopant atoms and impurities which may locally convert the material from one type to another type, the dislocation-oxygen interactions which alter the mechanical strength and warping resistance of silicon waters etc. The materials engineer has been at the forefront of these developments and also in the development of the technology for the fabrication and assembly of devices, manufacture of resistors, capacitors, insulators, transistors, diodes, etc. Without the development of appropriate materials, advances in electronics, communications and aero space technology would be impossible, Outstanding examples of developments heavily dependent on materials technology are the radio, the computer, the video, fibre optic telecommunications, to name a few.

5.3 Materials in Medicine

Materials technology is indispensable to medicine. Metals have been used in dental reconstruction for centuries, especially gold and mercury amalgams. Gold was particularly popular for false teeth until recently and there are nearly 200 compositions for this application. The scope has extended to the use of other materials placed superficially, sometimes with a part of it implanted or in contact with epithelial surfaces. Examples are percutaneous electrodes, haemodyalysis shunts, tracheostomy tubes, dental implants, contact lenses, intra-uterine contraceptive devices. Some materials are totally buried in body tissues such as in mammaplasty prostheses (breast reconstruction), bone fracture plates, screws, hip and joint implants, prosthetic heart valves, cardiac pacemakers, hearing aids, etc.

The relatively high success which has been achieved with metal implants has been due mainly to advances in metallurgical and materials engineering. Copper, silver and gold were used from ancient times until towards the end of the last century when emphasis shifted to other metals and alloys and, today, a wide variety of materials developed specifically for surgical implants is now available to the surgeon. Despite the rapid advance in materials implantation technology, the materials engineer is still confronted with very formidable problems. In the words of D.F. Williams, "Man lives in equilibrium with his environment, an equilibrium which has developed along with man himself. The more rapidly he changes that environment, the more closely we have to look at the way he perturbs this equilibrium. By actually implanting foreign substances into his body, we are highlighting this confrontation, and it is necessary to study the new situations that develop very closely, whether they are in equilibrium or non-equilibrium".[13]

The proliferation of this practice has provided a wide variety of tissue-materials confrontations which makes it difficult to extract even the major components of the general interfacial reaction. The body is a hostile environment for most materials. About 70 percent of the body weight comprises of rapidly flowing fluids and electrolytes comparable to sea water in salinity. As a result, many of these implants fail in service and surgery is often required to replace them. Also some materials are poisonous. This problem has opened up a relatively new and dynamic research area in materials technology, promoting active cooperation between the materials and medical disciplines to achieve greater improvements in the future in the durability and safety of implants and the development of new implantable devices. By careful diagnostic studies of failed implants, major contributory causes of failure often can be identified and remedied. However, this is a very complicated problem since, almost without exception, the failure of an implant cannot be attributed to a single cause. For the same reason, it is very difficult to predict the life expectancy of an implant. Some devices have been known to last 50 years in human tissue without any problem while others have given rise to inflamation, pains or failed completely within very short periods. Despite these problems, the scope of surgical implantation is increasing very rapidly and is no longer an exclusive preserve of the elderly, despite the words of D.F. Williams: "For we all know that, as we get older, we get silver in our hair, gold in our teeth, iron in our souls and lead in our feet".

6. THE MATERIALS CYCLE

Materials derive directly from the environment in which man lives. Man expends considerable energy in winning them, and even more energy in preventing or at least prolonging their return to the environment, for the biblical words are also true of materials: "From the earth we come and to the earth we shall return". This perception has given rise to a modern systems concept: 'The materials cycle' shown schematically in Figure 15. Raw materials are taken from the earth by winning; extracted, refined and processed into bulk materials, (metals, paper, glass, cement, etc.); fabricated into a myriad of products for societal use, (machines, electrical and electronic devices, etc.); and when they have played out their various assignments, they are discarded and become junk, either to enter the circuit again and again by recycling, or to return to mother earth from whence they came. The materials cycle is an enormous enterprise requiring enormous societal input in the form of knowledge, labour, energy and money for sustenance. At virtually every stage around the cycle, there are strong interactions among materials, energy and the environment and the systems concept affords an analytical framework for dealing with perturbations in the equilibrium of any of these three resource elements at any stage in the cycle. Let us briefly examine the materials-energy-environment system.

6.1 Materials and Energy

Nearly half the world's energy consumption is directly relatable to the mining, extraction, refining and processing of materials, iron and steel alone accounting for about 12 percent. It is inevitable therefore that any factor which affects the consumption of one will have profound repercussions for the other. In general, a material passes through several processing stages in the transformation from ore to finished product; mining, transportation, beneficiation, extraction, and mechanical processing. The energy consumption at each stage for a particular material is a function of the geological and geographical location of the ore deposit, the grade of ore, and the processing route. For example, copper

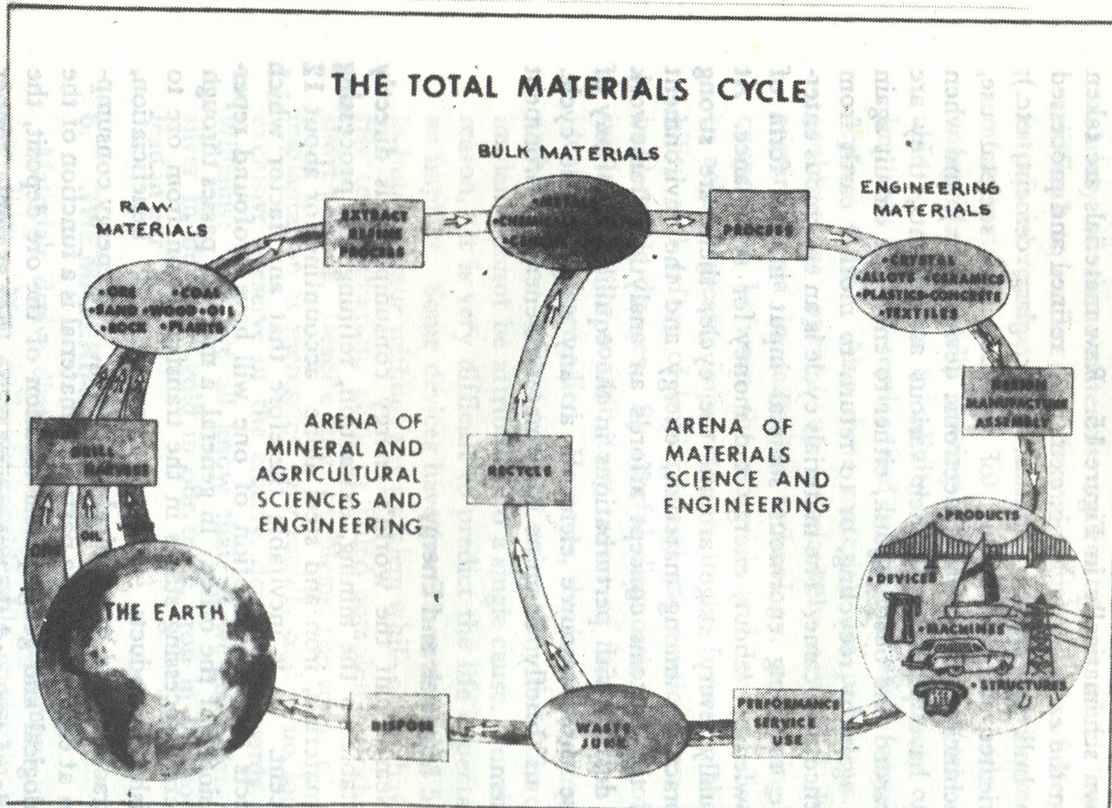

Figure 15: The Total Materials Cycle

ore contains only 0.5 to 0.7 percent copper and requires the processing of about 200 tonnes of ore to obtain 1 tonne of almost pure copper ingot (99.9%Cu) required for electrical circuits, with an energy input of about 120GJ. Much of the rich ore reserves of the world is depleting very rapidly and society is having to resort to poorer grades. It is anticipated that available copper ores for processing in the near future will contain no more than about 0.2 percent copper, requiring about 630 tonnes of ore to produce 1 tonne of copper ingot, increasing by a factor of 3 the energy requirement. The energy requirement for processing some important materials into primary products is listed in Table 2. The

Table 2:
Energy Requirement for Producing Primary Materials

Material	*Product*	*Energy/Ton Product (GJ)*
Steel (ore–BF–OH)	Ingot	24.3
Steel (scrap-electric) furnace	Ingot	11.0
Steel (Ore–BF–OC)	Ingot	25.1
Copper	Ingot	112.3
Aluminium	Ingot	244.0
Zinc	Ingot	65.0
Lead	Ingot	27.0
Magnesium	Metal	358
Titanium	Metal	408
Uranium (acid circuit)	Oxide	776
Uranium (alkaline circuit)	Oxide	1123
Uranium (Resin-in Pulp)	Oxide	795
Cement	Portland	7.6
Ceramics	Common brick	3.5
Ceramics	Basic Refractory	27
Ceramics	Fireclay	4.2
Glass	Glassware	17.4
Polystyrene	Plasticware	45.70
Polyethylene (low-density)	Plasticware	135
Paper	Paper product	18.0
Paper (recycled)	Paper product	5.4

example of copper extraction illustrates the crucial role of energy in materials processing. In fact, energy consumption has become a primary variable for assessing the efficiency of materials processing operations.

The world is under pressure to maximise the use of existing energy resources and develop new ones. One major limitation to the achievement of these objectives is the availability of appropriate materials. The drilling, handling and processing of crude oil pose very formidable materials problems, exacerbated by the current thrust towards the winning of off-shore deposits in highly corrosive environment. Materials problems severely limit progress in the area of electricity generation using coal, oil, gas, nuclear or solar power. Progress is slow in the development of unconventional sources of energy such as gasified coal, solar, nuclear, geothermal, wind, waste pyrolysis etc. mainly because of materials limitations. It is clear from the foregoing that materials and energy are inextricably interdependent.

6.2 Materials, Energy and the Environment

Since the environment is both the source and sink of materials and energy, it is inevitable that developments in both areas will have profound effects, usually negative, on the environment. Open cast mining is destroying vegetation and landscapes all over the world, a glaring example being the Jos tin mines. Effluents from materials processing are polluting the atmosphere and water resources of the world, posing serious hazard to human, animal and plant life. Perhaps the greatest threat comes from the nuclear industry which is considered the most important in meeting the world's long-term energy needs.

Since materials do so much damage to the environment, a retaliatory measure carefully designed by nature is pertinent. The environment is hostile to all materials, the degree varying between specific materials. Wood rots, metal rusts and corrodes, plastic degrades, glass tarnishes, ceramics weaken on exposure to the environment and a significant amount of effort in technological development is expended in finding new and more effective ways of protecting materials from the environment. Society is also becoming increasingly aware of the implications of continued, uncontrolled environmental damage and, already, environmental protection has become a significant constraint to the development of materials and energy resources. For example, the proliferation of nuclear plants has been slowed down considerably by societal pressure which has become more intensive in recent years. The future role of this source of energy in the world energy equation will depend on the extent to which the present problems of waste disposal are solved and the risk of accidents reduced. Some nuclear waste materials have to be sealed in containers and stored underground for some 25,000 years before they become harmless. One major problem is to develop materials for containers which can last so long.

6.3 Trends in Materials – Energy – Environmental Technology

Materials, energy and the environment constitute a resource system which has no national borders. All countries are linked by the processes and effects of supply, use, recovery and disposal of energy and materials. No country or even region possesses the materials and energy resources sufficient for its needs and no country is capable of protecting itself from the effects of the degradation of the common environment which results from the exploitation and use of energy and materials. The global economic and technological interdependence in problems relating to this resource system is becoming increasingly evident and there is a growing awareness of the need for a multi-national effort in solving problems of mutual interest. There is also increasing awareness of the potential effects of world materials and energy politics. The present problems of South Africa are directly relatable to the enormous mineral wealth of the region. The present manipulations in the world oil and tin markets are designed to bring the suppliers, most of which are in the developing world to their knees. Some years ago, a Nigerian visited an energy laboratory in the United States of America and when introduced to one of the scientists as a Nigerian energy expert, the scientist retorted "You OPEC guys queezed us on oil. In ten years, we will make you drink your oil". This statement is prophetic. One barrel of oil which was selling at $40 then now sells for much less than $20. We might well be drinking, bathing and cooking with oil in five years time!

On the materials scene, mining and processing methods are being improved to conserve energy and material resources. Now materials are being developed which can withstand harsh environment and make possible or sustain such important developments e.g. coal gasification, coal liquefaction, solar energy collection and storage, nuclear fission and fusion, space research, laser technology, deep sea mining, computer technology, hypersonic planes, etc. The trend in the energy scene is towards the conservation of energy in general and the shift of emphasis from oil to other more abundant sources of energy, in particular. coal, gas, solar energy and nuclear power, and waste pyrolysis. The present efforts in the conservation and protection of the environment will be intensified and new methods of processing waste to less potent forms will be developed. But perhaps one area in which technology is likely to make a very significant progress is in the recycling of materials because of its effect on materials availability, energy conservation and environmental protection. It is estimated that about 40 percent of the world requirement of metals, glasses, polymers, ceramics and fibres could be met by recycling, although not all waste materials offer the same possibilities for recycling, nor do they create the same environmental problems. Also, the potential for energy conservation varies significantly between metals. (See Table 3)

Table 3:
Energy Saving for Materials Production from Recycled Waste Compared with Primary Minerals

Material	*Energy Requirement (G J / Tonne)*		*% Energy Saving*
	From Primary Minerals	*From Recycled Waste*	
Aluminium	244	12	95
Steel (finished)	50.4	23.4	54
Glass	17.4	15	14
Paper	18	5.4	30

7. MATERIALS TECHNOLOGY FOR NATIONAL SELF RELIANCE

Nigeria is richly endowed with material resources including wood, iron ore, tin ore, lead-silver ore, columbite, molybdenite, manganese ore, clays, limestone, zircon sand, etc. The country also has abundant energy reserves including oil, gas, coal, uranium and solar energy. Despite these valuable gifts of nature, she does not appear to be making a significant progress towards industrialization. In fact, going back to the laws of relativity, the country is making negative progress. For, standing still means going down. A columnist recently compared the pace of industrialization in Japan and Nigeria. He aptly described Nigeria as that country which has everything and produces nothing and Japan as that which produces everything from nothing. It is pertinent here to examine briefly factors which have been responsible for this unenviable situation.

7.1 The Oil Doom

The oil boom of the early seventies which some of us prefer to call oil doom has been responsible in no small measure for staunting industrial growth in this country. There was enough money to buy whatever was needed from abroad and no sense of direction or purpose was identifiable. Inevitably, foreign entrepreneurs took advantage of the situation and initiated a large number of projects which contribute little or nothing to industrial development. For example, in 1970, there were only three soft drinks plants and about five breweries in the country. Today, there are sixty-six soft drinks plants and thirty-seven breweries, all of them operating almost entirely on imported raw materials. I once visited one of the top breweries many years ago and requested to know if any of the raw materials was locally sourced. The expatriate production manager had no remorse whatsoever in telling me and I quote: "The only local raw material input to our product is water and even that is unsuitable". It is significant that the same company recently announced in a national daily that it had found a way of replacing about 30 percent of imported raw materials with locally grown sorghum. Examples of such miracle discoveries abound in the industrial sector today, obviously a direct result of the current economic depression.

7.2 Government Policy

The perenial lack of a well articulated, coherent coordinated and realistic government policy has had an even more devastating effect on industrial development. This is clear from the few National Plans that have been developed so far. Projects were merely listed, usually with the assistance of foreign experts without due consideration of the country's capability. Many projects that were eventually embarked upon were either still-born or crippled. Two examples will serve to illustrate this problem:

7.2.1 The Automobile Industry

In pursuance of the strategy of import-substituting industrialization, government commissioned six automobile plants in the country in the last ten years, all of them assembly plants on turnkey basis. These comprised two passenger car plants and four commercial vehicle plants. According to the terms of the agreement between government and the foreign automobile companies, the backward integration and progression from assembly to manufacturing were virtually left to the discretion of the latter. For example, although the contract agreement specified that the car assembly plants must achieve a 50 percent local content by value within five years and 100 percent in thirteen years, a recent survey indicated that, after ten years of operation, neither plant has achieved more than 15 percent of truly locally manufactured local component input and this has been limited to components which require rudimentary technology. These include windscreen manufacturing which involves cutting up imported sheet glass and pressing to shape, production of ignition coil which merely involves the welding of a ready-assembled foreign-manufactured ignition coil to an imported clamp, petrol tanks constructed from three-piece, pre-pressed imported components, and batteries assembled from imported plate and shell components. The foreign partners in the car assembly projects claim that the contract was not explicit on who was expected to produce the local components and, in anycase, the appropriate materials are not available locally.

Furthermore, the proliferation of models has given a wide latitude for substantive product differentiation which makes local manufacture of components unattractive and uneconomical. It should be mentioned here that the companies have contributed in no small measure to this problem. In ten years of operation, one of the companies has introduced about ten models, some of them phased out after only a couple of years. At the last count, there were over a hundred models of automobiles on Nigerian roads.

The experience of India is relevant here. India which has a population at least ten times that of Nigeria commissioned only one car assembly plant which produced only one model in 1948. The model which was based on a famous British version has been retained to date. All the components are now manufactured locally and can be purchased even from a grocery store. The country is now planning the introduction of a new model which happens to be a phased out European model. An obvious advantage of this strategy is that the tooling can be purchased very cheaply and the production technology easily mastered. Surely, Nigeria has a lot to learn from this experience. Recently, it was announced that the Volkswagen Beetle which has been around for nearly fifty years without significant modification is to be phased out because it is being phased out in Europe and America. Perhaps the time is right for the adoption of this car as the Nigerian Peoples car for the next fifty years.

7.2.2 The Steel Industry

The Steel Industry has been a subject of severe criticisms in recent years because, despite the huge investments, it has made no significant impact on industrial development. None of the five plants in the country produces the grades and forms of steel that are required for manufacturing and all of them have problems, the most serious being the mismatch between the plants. Delta Steel Plant produces billets which it cannot transport to the satelite rolling mills located in Jos, Katsina and Osogbo which were planned to re-roll to finished primary products, hence the mills are importing billets. Ajaokuta Steel Plant is also importing billets because it requires a different size from that produced by Delta Steel Plant. Also, the installed capacity of the five plants requires about 40 percent of the total output of the National Electric Power Authority's generating capacity for operation. These are just three examples of deficient and uncoordinated planning which is evident in virtually every aspect of our industrialization policy.

7.2.3 *The Misconception of Technology Transfer*

A lot has been said and written about the failure of the developed countries to transfer technology to less developed countries, including Nigeria. It is naive to expect a voluntary transfer to technology since that would be a sure way of putting the developed world out of business. However, if an armed robber steals your car, the car has been transferred to him, though involuntarily. Japan refused to sign the international copyright laws for many years to avail itself of a more realistic alternative to voluntary technology transfer: 'copy technology'. This provided a strong platform for the take off of an aggressive industrial development. Up till today, Japan avoids 're-inventing the wheel', spends most of her energy in developing existing inventions and eventually sells the products to the inventors. Unfortunately, Nigeria was one of the first countries to sign the copyright laws.

8. SMALL IS BEAUTIFUL

This section is dedicated to E.F. Schumacher[14] who wrote and I quote "In industry, we can interest ourselves in the evolution of small-scale technology, relatively non-violent technology, technology with a human face." So far, Nigeria and indeed many other developing countries have been busy acquiring violent technology, technology with a monstrous face, technology that promotes negative development. In the developed world, the trend is towards giant, faster and automated machines with minimum human interference. In some countries, automobiles are now assembled almost entirely by robots. This sophisticated, highly capital intensive and labour-saving technology is fast becoming the exclusive preserve of the rich. Inevitably, the time has come for developing countries to evolve and promote vigorously a different kind of technology, small scale, more decentralised and more labour-intensive. Mahatma Ghandi said and I quote: "The poor of the world cannot be helped by mass production, only by production by the masses." This kind of technology has been named "Intermediate technology' by Schumacher and described as "the technology of production by the masses, making use of the best modern knowledge and experience, which is conducive to decentralisation, compatible with the laws of ecology, gentle in its use of scarce resources, and designed to serve the human person instead of making him the servant of machines." Fortunately, the current economic depression has motivated a strong drive towards the local fabrication of simple machines and spare parts and one can only hope that the momentum would not be short-lived. However, there is the problem of developing local inventions from research to commercial stage and provision of industrial extension service for potential investors. Some existing research institutes could be equipped to provide this vital missing link.

9. MATERIALS SCIENCE AND ENGINEERING AT IFE.

The engineer is one of the most maligned professionals in the world today, due mainly to the repercussions of his failures on mankind. The saying is true that the doctor buries his mistakes quietly but the engineer is buried by his mistakes. An aircraft crashes as a result of the failure of a small component and over 500 people die, a small pipe bursts and escaping poisonous gas kills over two thousand people and maims several thousands more. Sensational events like these tend to relegate to obscurity the innumerable positive achievements of engineering.

The engineer is also coming under increasingly severe if not unfair criticism for not taking account of the wider social and human consequences of his creations. Again, this is unfair because technology, like all power, is neutral. The negative or positive consequences depend on how it is used. In any case, the engineer hardly ever has any influence on the ultimate use of his inventions and it is difficult to see how he can be blamed for the negative effects which, in any case, are far outweighed by the benefits. To the day of his death, Rutherford detested any suggestion that his great atomic discoveries would ever be of any commercial use. Einstein never forgave himself for promoting the science which eventually led to the development of the bombs that destroyed Hiroshima and Nagasaki. Nevertheless, these criticisms underscore the need for a very sound training of the engineer, irrespective of the area of specialization. Not only must he achieve such a high level of competence which ensures that his failures and mistakes are minimized, but he must also appreciate that society wants technology which takes due cognisance of the social consequences of its advances.

This philosophy provided the inspiration for the character of technological education for which the University of Ife is famous. Metallurgical and materials engineering, one of the newest areas of specialization is no exception. Although the need for this development had been appreciated and planning had begun ten years previously, the first set of students was admitted to the programme only in 1979. There were two students and two staff under my humble leadership. It is not surprising that, at a 1:1 staff to student ratio, they both passed in Second Class Upper Division. Theirs was also the first set to graduate in Metallurgical and Materials Engineering in Black Africa. The growth of the Department in subsequent years has been phenomenal. There are now nearly 130 undergraduate students, seven postgraduate students and a strong group of academic and technical staff. My research activities have mainly been mission-oriented and may be viewed as mediation in the materials-energy-environmental confrontation. These activities may be grouped into three categories.

9.1 Energy for Materials

A coal research laboratory was established by me in 1971 and is so far the only one in existence in Black Africa. It analyses samples from many parts of Africa. The development of the facility was inspired by the need to solve a major raw material problem which has confronted a major sector of the Nigerian industry. The Ajaokuta Steel Plant is scheduled to be commissioned in 1989. It will require 1.3 million tonnes of coal a year in the first phase. increasing to 5.2 million tonnes in the final phase. Although Nigeria has abundant reserves of coal, they have no caking properties and are therefore unsuitable for metallurgical coking. Tests carried out by foreign experts have shown that no more than about 2 percent of local coals can be utilized by the plant and even this small proportion would present serious technical problems. In effect, Ajaokuta Steel Plant would have to import all its coal requirements. At the present international price of 150 U.S. dollars per tonne, the foreign exchange requirements for the first phase would be about 200 million dollars a year for coal alone, escalating to nearly 800 million dollars a year when the plant achieves the full design capacity of 5.2 million tonnes of steel a year, in addition to the wide range of other raw materials and spare parts.

Apart from the enormous foreign exchange implications, there are several other potential problem areas. Although coking coal constitutes a very small proportion of the total world reserves of coal, there is enough to meet the world requirements for iron making in the foreseeable future. Despite this, it is becoming increasingly difficult to find suitable, reliable and inexpensive sources of coking coal due primarily to the inequitable geographical distribution of coal in general and coking coal in particular. For example, about 85 percent of the total world reserves of coal and 75 percent of coking coal are located in North America, China and the U.S.S.R. It is not surprising that the international price of coking coal has risen by about 50 percent in the last five years and the foreign exchange outlay quoted above may be a gross underestimate by 1989 when the plant is expected to be commissioned. Apart from the foreign exchange implications, serious logistical problems of transporting imported coking coal from port to plant should also be anticipated.

It is clear from above that the problem of supply of coking coal to Ajaokuta Steel Plant is potentially serious and could constitute a major impediment to the viability of the plant. This prompted the initiation of a coal research project at Ife in 1970 with the primary objective of finding ways of maximising the use of local coals by the plant. Despite the shortage of funds, significant progress has been made. A comprehensive evaluation of all the coal deposits in the country has been made.[15-17] Fundamental studies on blend design and preparation have shown that, with slight modification to the conventional coking blend preparation, 25 to 30 percent of Enugu coal could be utilized by the plant [18-19] resulting in an annual saving of 70 to 250 million dollars in foreign exchange, depending on the output of the plant.

Extensive tests have also been carried out on the feasibility of producing metallurgical formed coke entirely from local coals. The results of the tests have been published in learned journals and were sufficiently encouraging to prompt the National Research Council of Canada to provide funds for me to design and build a research pilot plant at the Coal Research Laboratory, Ottawa in 1977. Some Nigerian coals were tested on the plant and the results confirmed that formed coke of metallurgical quality could be made entirely from Enugu coal or blends of Enugu and Lafia coals.[20-22] This would completely eliminate the need to import coal. My research activities in the area of coal utilization have yielded over ten major publications and twenty classified technical reports. The financial support for this project has been provided almost entirely by the University of Ife, for which I am deeply indebted to the university.

9.2 Materials for Energy

The pace of development of existing and new energy resources is being severely limited by the non-availability of appropriate materials. Most materials degrade to varying extent on exposure to the energy generation environment.

Special metals are required for constructing off-shore oil rigs, steam power generating plant, gas turbine generating plant, nuclear plant and solar power generating plant. Extensive research is going on all over the world to develop suitable materials for the various applications outlined above. Unfortunately, the materials developed so far created new fabrication problems. The thrust of my research in this area has been in the investigation of conditions under which some new and important energy materials could be processed into components. The most important contribution has been in the establishment of conditions under which some super-alloys and duplex-phase stainless steels could become super-plastic.

Superplasticity is the ability of metals to deform with exceptional stability in uniaxial tensile deformation. This leads to extremely large elongations, often greater than 1,000 percent without fracture, whereas for conventional materials equivalent values are usually much less than 100 percent. This phenomenon has important implications for industrial hot working practice. It means that complex components can be produced from high-strength alloys with little risk of fracture, thus extending the range of possible manufacturing techniques for these materials. For example, P/M IN-100 is a nickel base precipitation - hardenable superalloy developed basically as a cast alloy. The hot strength and specific strength make it particularly suitable for such high temperature applications as gas turbine blades, nozzles and wheels. However, the complexity of the alloy composition is such that severe segregation occurs during casting, resulting in poor hot ductility.

Recent developments have shown that this alloy can be produced in ultra-fine-grained form with considerably improved ductility by powder metallurgy techniques. My research work on this alloy was to determine the optimum range of conditions under which it becomes super-ductile in order to extend the range of processing options to such precision processes as forging and extrusion. It was established that the ultra-fine-grained superalloy can become superplastic if worked between 1000°C and 1150°C and at strain rates below 10^{-4} per second. It was possible to obtain elongations up to about 700 percent compared with less than 30 percent for a cast alloy.[23]

A new range of high chromium, high nickel stainless steels has been developed for applications requiring high strength at elevated temperatures. A highly stable duplex-phase structure can be developed in these materials by suitable heat-treatment which greatly enhances strength but depresses ductility, thus creating formidable forming problems. I have studied three varieties of this alloy, based on the 26Cr – 6Ni alloy over a wide range of microstructural, temperature and strain rate conditions and have established the optimum range of conditions for which super-ductility is possible. I have established also that, contrary to previous assumptions, superplastic behaviour is possible with relatively coarse-grained structure. This has very important implications for industry and could greatly simplify the complicated expensive technology of grain refinement, a primary prerequisite for superplasticity.[24–26] The studies on superplasticity in energy materials were jointly sponsored by Japan, the United States of America, and the University of Ife and have yielded five major publications.

9.3 Environmental Stability of Materials

It has been established in this lecture that materials, energy and the environment are closely inter-related and should be treated as three elements of a major resource system. Our work so far on energy for materials production and materials for energy systems has shown that environmental conditions can promote serious materials degradation. The studies on superplasticity of duplex phase stainless steels have shown for example that prolonged exposure of the materials to high temperature under stress can cause the precipitation of brittle phases which severly reduces hot ductility. Coal carbonization yields corrosive by-products which attack many materials. Studies have recently been initiated on the stability of materials in hostile environment under the sole sponsorship of the University of Ife.

10. CONCLUSIONS AND RECOMMENDATIONS

In this lecture, I have attempted to establish the crucial role of materials in the service of mankind and technology. I have also attempted to interrelate this vital resource with energy and the environment. I have discussed the relevant implications and outlined the contribution to international research efforts by the University of Ife. I wish now to make a few recommendations which might help in solving some problems of technological development of the country:

1. The pioneering effort of government in developing the materials industry, particularly steel has reached a critical mass and private entrepreneurship should now be encouraged, particularly in the upstream and downstream sectors.
2. There is an urgent need for a comprehensive and systems study of the national steel industry to identify problems, correct structural deficiencies, and determine the direction of development. It is gratifying to note the recent relevant statement in the Presidential Budget Speech, and I quote: "The public steel sector is in dire need of rationalisation. Work on the Ajaokuta plant will be prosecuted with determination, given the amount of money already sunk into the project and the relative irreversibility of the investment. However the delay of construction and start-up will now be turned into an advantage by using the plant to correct the structural distortion in the entire public steel sector."
3. The National Steel Council should be allowed to take off effectively after many years of inaction. The present situation whereby such a complex industry is run exclusively by a federal ministry is untenable.

4. The present practice whereby the international proprietary names of the products of imported technology are retained makes the local sourcing of components difficult. For example, as long the name 'Volkswagen' or 'Peugeot' is retained for locally assembled cars, every component must meet international specifications. Adoption of new names for these products would permit the re-design of components to suit local needs and specification of locally available alternative materials. This practice would not be peculiar to Nigeria. For example, the Lada which is being produced in the U.S.S.R. is in fact the Fiat 124 developed in Italy.

5. The proposed National Raw Materials Council should take off without further delay. The Council should develop a data bank on the national reserves and potential of mineral resources and should also develop expertise for the adaptation of locally available materials to the production of components for machinery and equipment.

6. Government should actively discourage the proliferation of 'Technology of Giantism' in favour of small and medium scale industries based on simple and easily mastered technology and thereby correct the negative demonstration effect of a sophisticated technology infiltrated into an unsophisticated environment.

7. There are many potential entrepreneurs willing to invest in upstream and downstream industries for the major sectors of the Nigerian industry, in petroleum, iron and steel, automotive industry, etc. Many are also willing to invest in local inventions. Some existing research institutes should be upgraded to develop and commercialise local inventions, and to provide advisory and extension services to entrepreneurs.

8. There is an urgent need for government to commission studies to determine the critical mix or manpower for full and effective technological emancipation by the

year 2,000 and to examine the extent to which the present system of education, particularly at the tertiary level can meet the needs. This could be done under the auspicies of the National Institute for Policy and Strategic Studies.

REDEDICATION

For some academics, this day signifies the beginning of the end of an active academic career. For me, it is the end of the beginning and a unique occasion to rededicate myself to a profession which I chose some twenty five years ago and have pursued religiously ever since, an occasion to re-affirm my personal, professional hippocratic oath:

To use my training and competence for the enhancement of the society which I serve,

To give the foremost consideration to her best interests,

To promote and enhance the status of the engineering profession,

And uphold its honour, glory and integrity.

So help me God.

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