

L
38

L29
'96
1997

**METAL FORMING:
THE UNAVOIDABLE LINK**

BY

SANMBO ADEWALE BALOGUN



**UNIVERSITY OF LAGOS PRESS - 1997
INAUGURAL LECTURE SERIES**

METAL FORMING:
THE UNAVOIDABLE LINK

3/26
L
36
L25
96
1997

METAL FORMING: THE UNAVOIDABLE LINK

An Inaugural Lecture delivered at the University
of Lagos on Wednesday, 13th August, 1997.

By

Prof. Sanmbo Adewale Balogun *FNSE*

*Department of Mechanical Engineering
University of Lagos*

Lagos.



University of Lagos Press
1997.

METAL FORMING: THE UNAVOIDABLE LINK
© S. A. Balogun - 1997

All rights reserved. No part of this publication may be used or reproduced without written approval of the author.

BY
Prof. Sambo Adewale Balogun FASE
Department of Mechanical Engineering
Lagos
First Published 1997

By

University of Lagos Press,
Unilag P.O. Box 132,
University of Lagos,
Lagos, Nigeria.

ISBN - 017 - 300 - 5



University of Lagos Press
1997

Introduction

Metalforming involves the shaping of metals into various forms. The end may be achieved simply by melting a metal and pouring it into a pre-shaped cavity. The product of this process is called a casting. When a solid metal is heated to high temperature and forced into a cavity by a compressive load, the metal is said to be forged. If the dimension of a metal bar or sheet is altered by forcing the bar or sheet to pass between two metallic solid cylindrical drums, then the metal is said to be rolled. Other metalworking processes include drawing, in which a wire or rod is pulled through a die orifice and extrusion, in which a heated metal is pushed with the aid of a ram through a shaped orifice to give various shapes and forms.

Metal shapes may also be formed from their powders. The powder is first compacted into a solid lump and then heated at high temperature to bond the powder particles. This process is called powder metallurgy. The last of the forming methods are the metal fabrication processes which include welding, brazing and soldering.

In this lecture, we shall trace the evolution of metal processing discuss some of the forming methods and highlight our involvement in the subject. We shall also attempt a review of the Nigerian Steel processing industry. Before all of these, however, we need to know a thing or two about metals which clearly is the heart of today's matter.

Metals

Metals are those ductile classes of engineering materials which are formed by metallic bonding. Metals possess high mechanical properties, good thermal and electrical conductivities and are amenable to various heat treatments to improve their properties. There are two broad groups of metals; ferrous and non-ferrous. Ferrous metals are iron and alloys of iron in which iron is the majority component. Non-ferrous metals are the other metallic elements and their alloys. Some common examples of non-ferrous metals are copper, zinc, aluminium, monel, brass and bronze. Cast irons and steels are the ferrous metals. Steels are alloys of iron and carbon in which the carbon content is not more than 2%. All other alloys of iron and carbon are cast irons. Carbon content in mild steels range from 0.1 to 0.3%, in high carbon steels 0.6 to 0.9% and in tool steels 0.9 to 1.4%. Commercial cast iron alloys have between 2.5 and 3.8%

carbon (Fig.1)

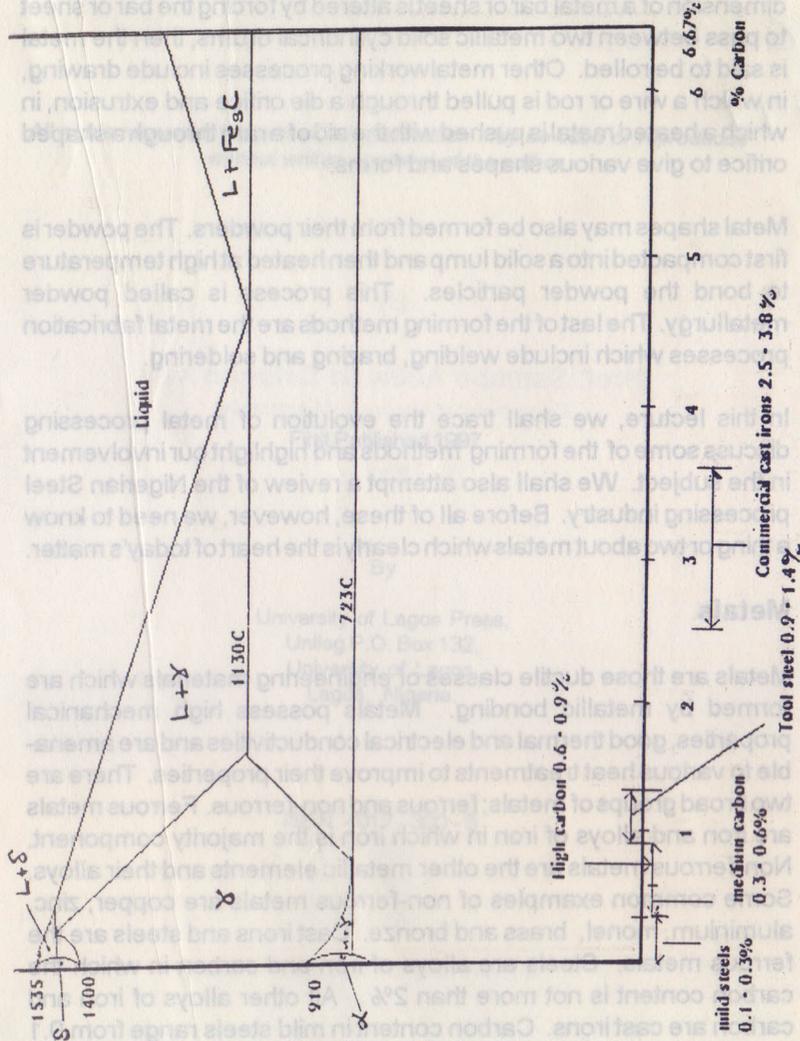


Fig 1: The Iron - Carbon Equilibrium Diagram

A critical factor in the manufacture of machines and engines is materials selection. Machine components and parts are often required to possess special properties like high hardness, high fracture toughness, high corrosion resistance, low ductility or high fatigue resistance as they may be subjected to various temperatures and stresses and unfavourable environmental conditions. The stresses may be tensile or compressive, shear or direct, vibratory or alternating, torsional or axial. Temperatures may be sub-zero, ambient or close to the melting point of the component while the environment in which the component operates may be acidic, basic or infested by bacteria, algae or fungi. The suitable metallic material must be able to withstand these stressing and environmental conditions without undue deterioration, deformation or failure.

Evolution of Metal Processing

The Copper Age

Archaeologists regard⁽¹⁾ the Bronze Age as the beginning of metal processing because the earliest copper-base artefacts were thought to be bronzes. This assumption has since been found to be wrong as evidence have been proved to show that high purity smelted coppers or coppers with small amounts of arsenic and antimony were in use long before the bronze age. Such copper artefacts were found in form of chisels and spatulas in Iran in 3800BC, flat axes in Egypt in 3500BC and axes in Israel in 3300BC. Most of the small artefacts were made by hammering while the larger ones such as hammer-axes were cast from native copper.

The copper age took off effectively after 3500BC when the Summerian city states of lower Euphrates and Tigris which made wide use of copper were established. Climatic and ecological conditions rather than proximity to Anatolia and Iran seem to have determined how soon the practice of metallurgy which was copper smelting, reached various countries around the area. The copper age thus reached India through Harappa and Mohenjo-Daro, the two famed pre-historic civilizations of the Indian Sub-continent between 3000 and 2300 BC. It reached Russia and the far east around 2000BC. British Isles at about 1900BC and Mexico in 1500AD.

The Bronze Age

Mesopotamia appears to be the source of the earliest bronzes between 3000 and 2500BC when real tin bronzes with 8 to 10% Sn were found in royal graves there. The Bronze Age was spread to Egypt in 2600BC, Syria and Palestine in 2200BC and Italy between 1900 and 1800BC. By 2000BC, many Chinese artefacts had been made in tin bronzes. Central Europe acquired the bronze processing capability between 1800 and 1500BC and South America got involved between 1000 and 1540AD. The famed bronze works of Nigeria were to be established in the seventeenth century for decorative and artistic purposes.

Change in forming technique was the major difference between the early and late Bronze eras. Whereas the early objects required forging and hammering to confer desired shape, subsequent ones were mainly cast in two-part moulds thus heralding the beginning of the metal casting processes. Even as early as then, lead was already being added to the melts to improve fluidity and to ease the production of intricate shapes. The Bronze era, however, witnessed little changes in the melting and casting techniques. In late Bronze age Palestine, square stone boxes served as melting crucibles in which metals were melted and energy for melting was provided by charcoal arranged in such a manner as to provide air from below or from the side or air is blown in with the aid of bellows. Very little is known, from archaeological findings, about the bellows used at the time but they are reputed to be as simple as the African blacksmith's bellows in current use.

Moulds were made of stone, clay, copper or bronze. Such moulds were often of the open type but sometimes some had matrices carved into the sides for the production of awls, chisels and knives which were later forged into the final shape. Clay moulds are fragile and are, therefore, not in widespread use for metal casting. Bronze moulds are heavier than stone moulds. They distort after repeated heating and deteriorate when hot metal gets welded to a badly finished cavity. Bronze moulds, however, have the advantage of not suffering from thermal shock which would cause cracking in stone moulds.

During the late Bronze era, remarkable progress was made in fabrication and joining. Various tools like chisels, punches, socketed hammers, etc, were made for wood, stone and metalwork. Two-

handed saws for cutting were also known to have been in existence during the period.

IRON AGE

Asia Minor is credited, in the literature, as being the cradle of the Iron Age which began around 2000BC. Iron making technology reached Anatolia and Iran between 1500 and 1000BC, and spread thereafter to Palestine. The Phoenicians had the iron working knowledge at this time and soon spread it to Western Mediterranean and Carthage. Greek mercenaries spread the new technology to Sudan through Egypt or Mesopotamia, South Arabia and Ethiopia around 200BC. Nigeria acquired the iron working knowledge through North Africa, between 400 and 300 BC when the Nok culture smelted iron.

The Nigerian metal of the time was reputed to show "an extraordinary degree of purity and freedom from slag inclusions". Nigeria was to spread the iron smelting knowledge through her migrants to central and East Africa around 500 AD and to South Africa around 1000 AD.

POST MEDIEVAL METALLURGY

The development of metallurgy in the post-medieval era is quite interesting. A prolific German scientist called Agricola had given tremendous publicity to German metallurgy in his works that so many governments invited German workers to develop their mineral resources. One of such governments was that of Queen Elizabeth 1 of England (1523-1603) who was suspicious of the enormous military might of Spain and would rather ensure her self sufficiency in metals by seeking aid from abroad. According to Tylecote⁽³⁾, the invitation of Agricola arose because of the common feeling in the Britain of the time that foreigners knew more about everything than the British.

The post medieval period which began around 1500AD saw significant progress in furnace development. It was the period the earliest blast furnaces were built in many parts of Europe and China. There was also progress in the development of rolling and slitting facilities and in copper refining and extraction of silver from lead.

THE INDUSTRIAL REVOLUTION

The industrial revolution period between 1720 and 1850 witnessed effective transition to the use of coke and coal instead of charcoal in iron making. It witnessed also great strides in furnace construction, coke making, ore roasting, iron and steel making, development of iron foundries and the smelting and refining of various non-ferrous metals. Many metal working machines for rolling and slitting, boring and cutting and forging and hammering were built during the period.

METAL PROCESSING

Adepoju⁽²⁾ has aptly described the life cycle of ferrous metals as being from "dust to dust". The cycle begins with the metal's occurrence in the earth's crust as dusty compounds, usually oxides. These are the ores of the metal. The metal is then extracted, refined and formed into shape before use as machine or structural components, farming tools or even a piece of furniture. Various forms of heat treatment might be applied to the metal to confer the properties that would enable it perform the functions for which it was designed. When finally discarded after its useful life, the metal is dumped in a waste heap where it deteriorates, under the influence of the environment, into a heap of oxide dust.

The main ores of iron are haemetite Fe_2O_3 , magnetite Fe_3O_4 , limonite $\text{Fe}_2\text{O}_2 \cdot \text{H}_2\text{O}$ and siderite FeCO_3 . After mining, the ore is beneficiated by removing some of the gangue to improve the efficiency of iron extraction. In this way, a larger quantity of iron is produced for a unit quantity of energy consumed.

IRON AND STEEL MAKING

The major iron making processes in current use are the *blast Furnace* process and the *Direct Reduction* process. In the blast furnace process, the ore is reduced with carbon monoxide while in the direct reduction process, the ore is reduced directly by the carbon in the fuel. Iron is subsequently converted to steel by addition of steel scraps and Ferro-alloys like Ferro-silicon, Ferro-manganese etc in open hearth furnaces, converters or electric arc furnaces and cast into ingots or blooms. Slabs and plates may, however, be produced instead of ingots by the continuous casting process (Fig.2).

METAL FORMING

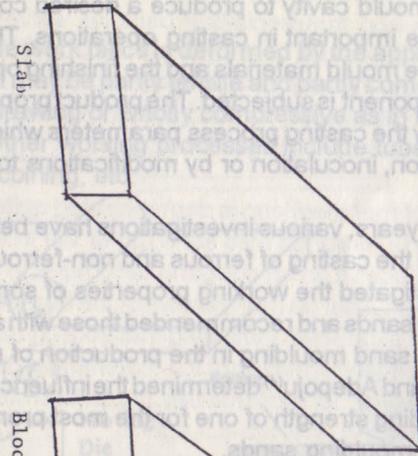
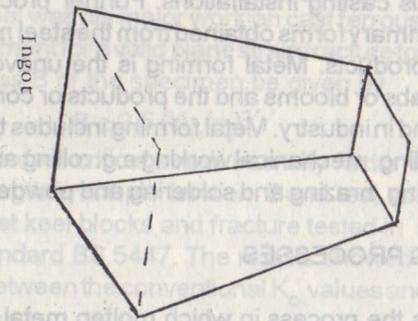


Fig.2: Primary Cast Forms

METAL FORMING

The products of steel making processes are ingots if the melt are teemed into ingot moulds or slabs or blooms if routed through continuous casting installations. Further processing is required to turn the primary forms obtained from the steel making processes into finished products. Metal forming is the unavoidable link between ingots, slabs or blooms and the products or components used in our homes and in industry. Metal forming includes the casting processes e.g. founding, mechanical working e.g. rolling and forging, fabrication e.g. welding, brazing and soldering and powder metallurgy.

CASTING PROCESSES

Casting is the process in which molten metal is poured into a pre-shaped mould cavity to produce a desired component. Three elements are important in casting operations. These are the melting facility, the mould materials and the finishing operations to which the cast component is subjected. The product properties are determined largely by the casting process parameters which may be influenced by vibration, inoculation or by modifications to the gating system.

Over the years, various investigations have been carried out here in Lagos on the casting of ferrous and non-ferrous metals. Balogun *et al*⁽³⁾ investigated the working properties of some Nigerian synthetic moulding sands and recommended those with acceptable properties for green sand moulding in the production of non-ferrous castings. Balogun and Adepoju⁽⁴⁾ determined the influence of some additives on the moulding strength of one for the most promising of the Nigerian synthetic moulding sands.

And in response to a request from industry, Balogun and Adepoju^(5,6) investigated the effects of some mould materials on the mechanical properties of some binary aluminium alloys and the effect of sand grain size and texture on some properties of cast aluminium. To improve mechanical properties obtained from some industrial foundry processes, Adepoju and Balogun investigated the effects of melt vibration on the texture and mechanical properties of Aluminium and leaded gun metal. Much later in 1989, Adepoju, Ogo and Balogun⁽⁶⁾ investigated the effect of low frequency vibration on the cast structure and mechanical properties of basis and free cutting brasses.

Beside our study⁽⁹⁾ of the influence of alloy composition and vibration on the ultrasound attenuation in some austenitic stainless steels, Balogun's application⁽¹⁰⁾ of the double torsion text technique for the determination of the plane strain fracture toughness of a chro-moly-vanadium cast steel was his major work on cast ferrous metals. The ASTM size requirement for a valid plane strain fracture toughness test is that the thickness B of the specimen be given by

$$B \geq 2.5 (K_{Ic} / \sigma_y)^2$$

Where K_{Ic} is the Mode 1 critical stress intensity factor and σ_y is the material yield strength in simple tension. Bend test samples were machined from cast keel blocks and fracture tested in accordance with the British standard BS 5447. The results showed remarkably good agreement between the conventional K_{Ic} values and the double torsion test results.

METAL WORKING

In metal working, the work piece is deformed by the application of a primary force which may be partly tensile and partly compressive as in rolling and wire drawing or wholly compressive as in forging and extrusion (Fig.3). Other working processes include tube and deep drawing, spinning, coining, etc.

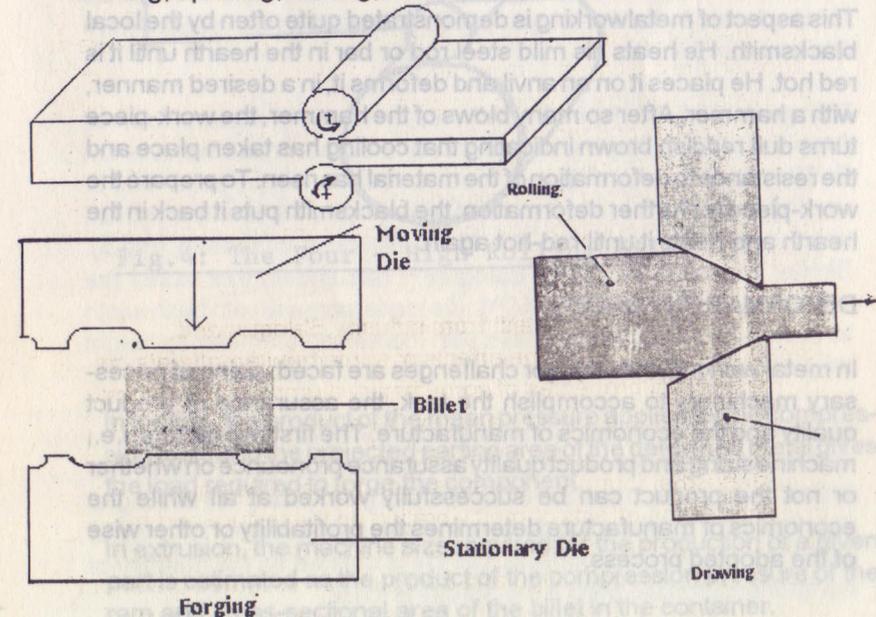


Fig 3: Metalworking Processes

Most metal working operations are done hot. Metals having low resistance to deformation, like lead and Aluminium may be worked cold. Cold working may also be applied as a finishing operation as in rolling:

- (a) to permit deformation to a thickness not normally achievable in the hot process.
- (b) to confer better surface finish to the product and
- (c) to allow the achievement of closer dimensional tolerance.

Worked metals are stronger than the unworked. The mechanism of strengthening derives from the effects of various defects such as grain boundaries, stacking faults and dislocations. The application of deformation energy causes grains to deform and slips to occur on various slip systems in the work-piece. The grain boundaries, the solute atoms and the precipitate particles serve as barriers to the movement of dislocations. Dislocation pile up occurs at these barriers to give rise to the strengthening observed. Further deformation of the work-piece would be difficult except the stresses generated are first relieved by some annealing processes.

This aspect of metalworking is demonstrated quite often by the local blacksmith. He heats his mild steel rod or bar in the hearth until it is red hot. He places it on an anvil and deforms it, in a desired manner, with a hammer. After so many blows of the hammer, the work-piece turns dull reddish brown indicating that cooling has taken place and the resistance to deformation of the material has risen. To prepare the work-piece for further deformation, the blacksmith puts it back in the hearth and heats it until red-hot again.

DEFORMATION FORCES

In metal working, three major challenges are faced: sizing of necessary machinery to accomplish the task, the assurance of product quality and the economics of manufacture. The first two factors, i.e., machine sizing and product quality assurance pronounce on whether or not the product can be successfully worked at all while the economics of manufacture determines the profitability or other wise of the adopted process.

Appropriate machine size is often determined by the resistance to deformation of the material and the cross-sectional area of the work-piece onto which the tool delivers the straining energy. In strip rolling, for instance, the product of the area of contact between the rolls and the strip and the resistance to deformation of the work-piece gives a reasonable assessment of the load required to roll the strip. Consequently, the area of contact is kept low by using very slender steel work-rolls and reinforcing them with rigid cast iron back-up rolls to prevent bending of the work rolls during the rolling process (Fig. 4).

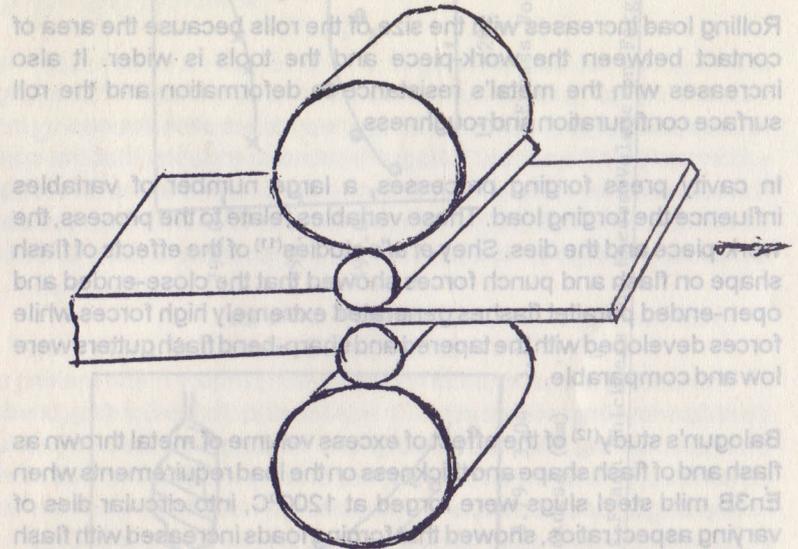


Fig.4: The Four - High Rolling Mill

In forging, the product of the mean pressure applied by the compression tools and the projected parting area of the deformed metal gives the load required to forge the component.

In extrusion, the machine size required for the production of a given part is estimated as the product of the compression pressure of the ram and cross-sectional area of the billet in the container.

From these examples, machine size would be quite easy to determine were the areas of surfaces on which the deformation stresses to be delivered constant, the operating stresses invariable and the resistance to deformation of the work-piece homogeneous. This, unfortunately, is hardly ever the case. The metalworker, thus, has to determine the inter-relationships between various process parameters to find as close as possible an estimation of the load requirement. To overload a machine is to damage it and to under load it is to incur avoidable higher overhead expenses which will raise the unit cost of the product and reduce profitability.

Rolling load increases with the size of the rolls because the area of contact between the work-piece and the tools is wider. It also increases with the metal's resistance to deformation and the roll surface configuration and roughness.

In cavity press forging processes, a large number of variables influence the forging load. These variables relate to the process, the work-piece and the dies. Shey *et al's* studies⁽¹¹⁾ of the effects of flash shape on flash and punch forces showed that the close-ended and open-ended parallel flashes generated extremely high forces while forces developed with the tapered and sharp-bend flash gutters were low and comparable.

Balogun's study⁽¹²⁾ of the effect of excess volume of metal thrown as flash and of flash shape and thickness on the load requirements when En3B mild steel slugs were forged at 1200°C, into circular dies of varying aspect ratios, showed that forging loads increased with flash volume and decreased as the flash thickness increased (Fig.5). Similar experimentation by Balogun⁽¹³⁾ has shown that within the temperature of 1150°C to 1250°C, die loads increase with flash width to thickness ratio and decrease with increasing diameter to height ratio and slug temperature.

Dies used in forging operations are made of very expensive tool steels and a pair of dies is normally sunk for a specific order. Thus, in one breadth, the order must be reasonably large to justify the sinking of the dies, on the other, the dies must have a reasonably long life to make the process economical. Die life is defined as the quantity of components forged before the die starts to fail.

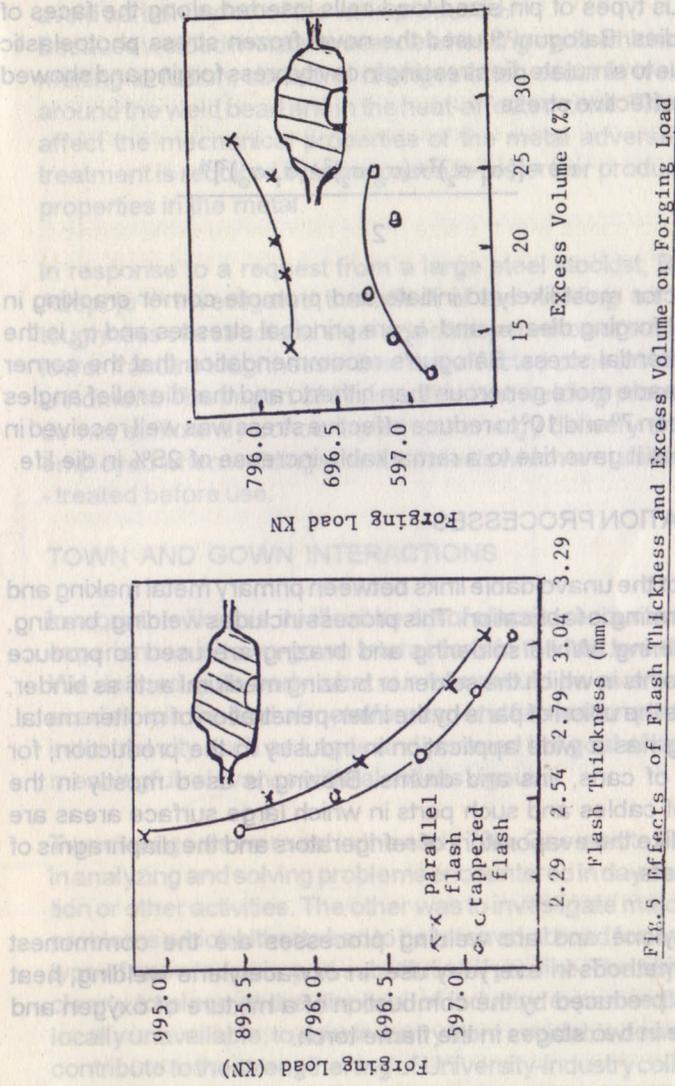


Fig.5 Effects of Flash Thickness and Excess Volume on Forging Load

Because impressions in cavity die forging are often so complex, complete analytical treatment of the problem has always been unreliable. Up to 1979, experimentation on die stressing were restricted to the determination of normal stress distribution by the use of various types of pin-sized load cells inserted along the faces of forging dies. Balogun⁽¹⁴⁾ used the novel frozen stress photoelastic technique to simulate die stressing in cavity press forging and showed that the effective stress

$$\sigma_e = \frac{[(\sigma_1 - \sigma_2)^2 + (\sigma_\phi - \sigma_2)^2 + (\sigma_1 - \sigma_\phi)^2]^{1/2}}{2}$$

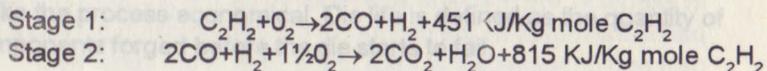
2

is the factor most likely to initiate and promote corner cracking in industrial forging dies. σ_1 and σ_2 are principal stresses and σ_ϕ is the circumferential stress. Balogun's recommendation that the corner radii be made more generous than hitherto and that die relief angles be between 7° and 10° to reduce effective stress was well received in industry as it gave rise to a remarkable increase of 25% in die life.

FABRICATION PROCESSES

The last of the unavoidable links between primary metal making and shape forming is fabrication. This process includes welding, brazing, and soldering. While soldering and brazing are used to produce surface joints in which the solder or brazing medium acts as binder, welding is the union of parts by the inter-penetration of molten metal. Soldering has a wide application in industry in the production, for instance of cans, tins and drums. Brazing is used mostly in the jointing of cables and such parts in which large surface areas are involved like the evaporators of refrigerators and the diaphragms of thermostats.

Oxy-acetylene and arc welding processes are the commonest welding methods in everyday use. In oxy-acetylene welding, heat energy is produced by the combustion of a mixture of oxygen and acetylene in two stages in the flame torch.



In arc welding, arc is struck either between base metal and the

electrode or between two electrodes by the passage of an open circuit current through the electrodes. Where arc is struck between the work-piece and a carbon electrode, the electrode is connected to the negative terminal of the power supply to assure stability of arc and to avoid carbonization of the weld produced.

Because welded metal experience a heating cycle which ranges from melting to fusion, structural changes often occur in welded metals around the weld bead and in the heat-affected zone. These changes affect the mechanical properties of the metal adversely and heat treatment is required in some cases to restore or produce desirable properties in the metal.

In response to a request from a large steel stockist, Balogun and Adepoju⁽¹⁵⁾ investigated the effect of arc welding on the fracture toughness of a structural steel and discovered to our surprise a much lower fracture toughness in the heat affected zone (HAZ) than in the weldment. The import of this result is that welding processes which do not sufficiently concentrate heat energy delivery should not be employed when welding structural steels which are unlikely to be heat-treated before use.

TOWN AND GOWN INTERACTIONS

In moments like this, it will not be out of place to recount some of one's experiences in town-gown interactions in the last twenty-five years. We defined quite early what our role should be as an experimental academic in the field of metalforming and fabrication particularly in an industrial city such as Lagos and pursued the goal of ascertaining a meaningful relevance with relentless vigour.

Two clear goals were set in the early 70's. One was to assist industry in analyzing and solving problems encountered in day-to-day production or other activities. The other was to investigate major production problems which hitherto had to be referred abroad for investigation—a type of knowledge import substitution if you like. The objectives were clearly to place at the disposal of industry expertise thought to be locally unavailable, to save industry from avoidable downtimes and to contribute to the strengthening of University-industry collaboration. In this regard we are pleased to review three of such interactions that solved problems that were considered truly difficult at the time and gave meaningful expression to our quest for relevance in the field.

1. The Roll-Neck Failure Problem

A big Lagos oil - milling firm extracted oil from palm kernels in commercial quantities. Crushing was with the aid of two-high non-reversing roll-crushers (fig. 6). The company discovered that the crusher-rolls often failed at the necks before the prescribed life span of the rolls were reached. This caused great disruptions in production, increased the cost per tonne of the palm kernel oil (PKO) and other by-products and made very difficult, if not impossible, the amortization of the capital outlay in the production facilities.

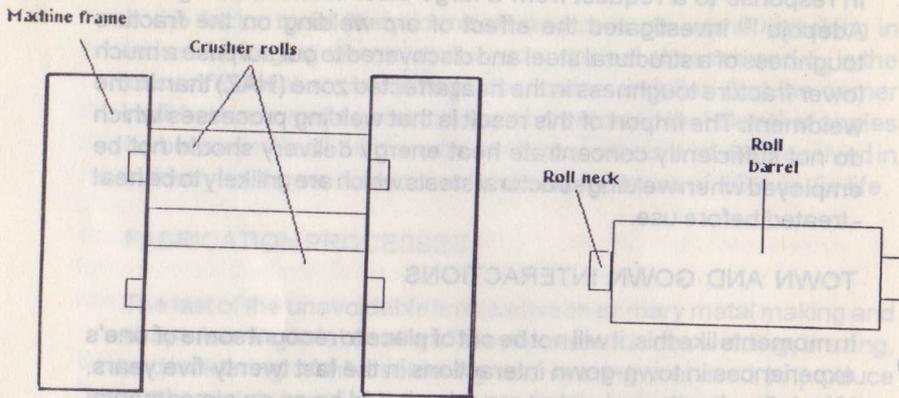


Fig 6: Crusher Mill Set-up and Crusher Roll

We were conducting our final year students round the works in 1978 when at the crusher store we noticed a large stockpile of dis-used rolls that have all failed around the neck region. The production manager informed us that they were going to invite an expert from abroad to investigate the failures and pronounce on what was responsible for the failures and to prescribe how such failure would be eliminated in future rolling operations. We offered to carry out the failure analysis, at the time free of charge.

Abati-Sobulo and Balogun⁽¹⁶⁾ studied carefully the kernel processing procedures, the mill set - up, the raw stock feeding method, the loading procedure, the crushing speed and the mass flow rates. Samples of the failed sections were cut for laboratory examination. After exhaustive shear and bending analyses and mechanical and metallographic examinations of specimens from the failure zones, we came to the right conclusion that the configuration of the roll body was inappropriate and recommended an alternative design, based on our findings, which would eliminate the problem for good.

2. The Fir-Tree Defect Problem

At the instance of one of our senior colleagues who was a close friend of the then chairman of the company, an Ikeja Steel rolling mill invited us sometime ago, to visit their factory to investigate what was clearly a very disturbing problem. The company rolled mild steel bars and rods of various sizes for the construction industry. They had a small foundry in which they produced mild steel billets from local steel scraps and rolled them on single-stand three-high reversing mills. To supplement the billets produced in their works, the company procured rolled steel plates from abroad and cut them up into billets to serve as raw stock for the production of construction rods. This grade of billets was the source of their problem.

The company had a very large consignment of the plate delivered to their works. Billets were cut from the plates, heated in the company's oil-fired furnaces and were to be rolled into 20mm reinforcement rods when during the first two passes the billets invariably split at various points on the edges to give a shape resembling a fir-tree (Fig.7). We

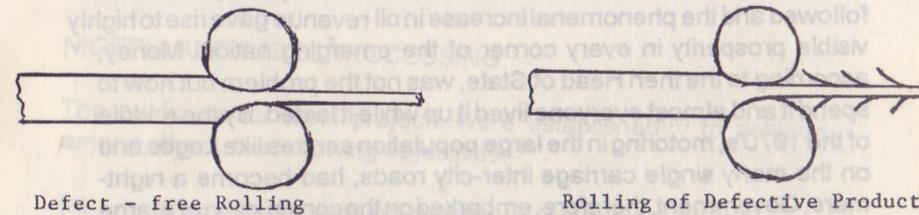


Fig.7: Fir-tree Defect

cut samples from some of the defective rolled products and obtained the production history of the raw material from the company.

After five days of rigorous examination, nothing was found in the production history of the billets or in their macro or microstructure to suggest the cause of the edge tearing resulting in the fir-tree defect. We visited the plant again, took another curious look at the billet heating process and discovered nothing. We returned to our laboratories in dejection to continue the search for the elusive cause of the anomalous deformation. One cool morning two days later, we decided to grind and polish for examination some other faces of the micro structural sample we were studying and "lo and behold", there lay the clue! The billet grains had severe preferred orientation and the workmen had cut all the billets across the direction of preferred orientation. The effect was differential slip at various points at the edges as roll pressure was applied. Slip occurred in various directions but mostly at a specific angle to the rolling direction hence the disproportionate strain at various points on the work-piece and the attendant appearance of the fir-tree defect.

We prescribed a viable billet parting direction and a rational rolling schedule which reduced the percentage deformation per pass and increased the number of passes by one. This way the problem was solved and the remaining large stock of raw materials was saved for the company.

3. The Weld Crack Problem

The unfortunate Nigeria Civil War ended in 1970. The peace that followed and the phenomenal increase in oil revenue gave rise to highly visible prosperity in every corner of the emerging nation. Money, according to the then Head of State, was not the problem but how to spend it and almost everyone lived it up while it lasted. By the middle of the 1970's, motoring in the large population centres like Lagos and on the many single carriage inter-city roads, had become a nightmare. Government, therefore, embarked on the construction of a large number of road networks and flyover bridges to alleviate urban traffic congestion, facilitate inter - highway linkage and eliminate bottlenecks.

A large construction company had a contract to build some flyover bridges in the South West part of the country. The contractor mobilized to site in earnest and construction work continued with vigour. Then at a stage in the construction programme, we had a request from the contractor to investigate in the shortest possible time the cracking that was occurring in some structural steel members that were being welded together. The problem had become quite worrisome because it was threatening to stall progress of work and extend the completion period of the project. This is aside of the expensive losses in materials being incurred as cracked structural members could not be used in the construction of heavy load bearing sections like the span on a bridge.

We took a small sample of the steel and after extensive investigation in our laboratories, we discovered that the welding procedure adopted for the steel was inappropriate. The material differed substantially in composition and texture from steels that would not crack after welding. The cracks were occurring because of carbide precipitation in the grain boundaries as the steel temperature was raised quickly from ambient temperature to beyond its melting point by the arc-welding torch. Our task was to recommend procedural changes in the welding process that will stem the cracking by preventing carbide precipitation at the grain boundaries. Forty eight hours after receiving the steel sample from the site, we were able to suggest, on the strength of our investigation, that the steels should be pre - heated to a temperature some 55°C above the ambient temperature of the steel sample. We are pleased to recall that our prescription solved the problem completely.

NIGERIA AND STEEL PROCESSING

The public sector steel projects were established⁽¹⁷⁾ to achieve, among others, the following objectives:

- (a) provision of a solid industrial base for Nigeria's technological development.
- (b) promotion of modern technology transfer and acquisition.
- (c) conservation of the country's foreign exchange through the reduction of the outflow of funds for the importation of iron and

- steel products and related raw materials.
- (d) stimulation of export promotion in order to optimize the use of the country's total available resources beyond crude petroleum.
 - (e) creation of employment opportunities in the steel plants and related industries.

The idea of a steel project was first mooted in 1958. Various studies conducted between 1961 and 1965 on the feasibility of steel raw materials in the country produced negative results. Then in 1967 a UNIDO report encouraged Government to commission Messrs. V/O Tiajpromexport (TPE) of Russia to study the occurrences and extent of raw materials deposits for iron and steel production in the country. The firm recommended that a 1.3m tonne/year integrated steel plant with a provision for expansion to 2.6m tones in the second phase and 5.2m in the third be established at Ajaokuta for the manufacture of long and flat products. The TPE report was accepted but with a modification that the plant should manufacture only long products ostensibly to satisfy the huge demand for steel rods and bars in the then flourishing construction industry.

The decision was, however, to be regretted⁽¹⁷⁾ later when it was realized that the approved product mix of the plant would not adequately serve the long-term strategic needs of the country and a modification to include the production of flat products was to cost enormously more than it would have cost if the original recommendation was accepted. The modification has contributed, in no small way, to the delay of the Ajaokuta steel project.

The proposed Ajaokuta plant was to comprise a sinter plant, a coke oven plant, a single blast furnace, a lime plant, a basic oxygen steel making plant, continuous casting machines and rolling mills. The plant's rolling mills are made up of

- (a) a 130,000 tonnes/year wire rod mill for the production of rods and reinforcing bars
- (b) a 550,000 tonnes/year medium section mill for the production of beams, channels, angles and bar flats; and
- (c) a 400,000 tonnes/year light section mill for the manufacture of angles, bars, flats, squares and hexagons.

Construction of the plant began in 1981 and by 1983, one of the rolling

mills was commissioned. In the same year, two of the Western European Civil contractors demobilised from site because jobs done were not paid for. Erection works consequently came to a standstill. By the time the contractors went back to site almost eight years later, the project cost had escalated. The sharp rise in costs resulted mainly because of

- (a) The inability of Government to pay as construction work progressed because of economic recession and the attendant cost over-runs.
- (b) The increased wage bills and rises in costs of construction materials and
- (c) The high cost of variations arising from modifications to the specifications of certain units after construction has begun as in the cases of the inclusion of rail products in the medium section and structural mill and planned introduction of facilities for the rolling of plates, strips and sheets.

Today the fate of Ajaokuta Steel Company is as uncertain as it has always been. No one has confirmed the speculated cancellation of the Ajaokuta Steel contract, nor has necessary funds been provided for a prompt completion of the project reported to be 98% completed in the last six years. The current estimate of the remaining 2% construction is \$217m or N18.5 billion and another \$100 million may be required for the refurbishment of machines that have been unused for a long time and the rehabilitation of vandalized plants and machinery as well as for provision of working capital.

THE DELTA STEEL COMPANY (DSC)

The Delta Steel Company is designed to produce one million tonnes of steel per year. Iron making is by the Mildrex Direct Reduction process, steel making by the Electric Arc process and billet production by continuous casting. The plant is designed to roll 370,000 tonnes of its installed capacity into rounds, bar flats, equal and unequal angles, tees and channels and to supply each of the inland rolling mills 210,000 tonnes of billets annually. Contract for the plant was awarded on turnkey basis to a consortium of Austrian and German firms in 1977 and by 1982, the project was commissioned.

Since then, the plant has been running in fits and starts and has not been able to fulfil its mission. Table 1 shows the liquid steel production record of Delta Steel Company between 1982 and 1993.

Year	Production (Tonne)	Capacity Utilisation (%)
1982	91,000	9.1
1983	181,957	18.2
1984	180,318	18.0
1985	243,893	24.4
1986	134,067	13.4
1987	136,552	13.7
1988	139,326	13.9
1989	127,246	12.7
1990	138,950	13.9
1991	113,802	11.4
1992	61,871	6.2
1993	20,580	2.1

Table 1: DSC Liquid Steel Production Record (1982-1993)⁽¹⁸⁾

With a maximum capacity utilisation of 24.4% the plant never really got off to a credible start. The effect of this dismal steel making performance was that the plant has not been able to meet the billet needs of its own captive rolling mills let alone meet the orders of the inland rolling mills which were to depend entirely on the company for their rawstocks.

Table 2 shows the capacity utilization of Delta Steel Company's captive rolling mills.

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Capacity Utilisation (%)	26.0	22.3	17.9	19.4	16.3	18.5	9.4	6.6	3.9	3.4	2.1

Table 2: Capacity Utilization of DSC Rolling Facilities

The down times that occurred in the various units of the Delta Steel complex in 1986 when production quantities first dipped and has since not recovered are as shown in table 3 below.

Units	Down Times (%)	
	First Quarter	Second Quarter
Rolling Mill	77.8	63.6
L. E.	75.1	65.2
Direct reduction plant	77.8	42.8
Pellet Plant	86.1	58.9
Lime Plant	80.6	38.8

Table 3: DSC Downtimes in 1986

Table 4 highlights the constraints that militated against smooth and large-scale production in the first two quarters of 1986.

Causes of delay	Down times(%)	
	First quarter	Second quarter
Equipment breakdown	47.9	31.2
Operational Delay	15.1	32.2
Lack of auxiliary service	19.4	14.2
Lack of materials	8	12.5
Power outages	2.6	5.2
Other	7.0	4.7

Table 4: DSC Constraint Categories in 1986⁽¹⁸⁾

The table indicates that equipment breakdown was the biggest constraint to production, followed by lack of materials and operational delays. The trend has since changed as lack of materials and equipment breakdown arising from gross under capitalisation (underfunding) are now the most significant constraints to production.

THE INLAND ROLLING MILLS

The three inland rolling mills are located in Oshogbo in Osun State, Jos in Plateau State and Katsina in Katsina State. The mills were commissioned at the end of 1982. Each plant has a capacity of 210,000 tonnes per year with a plan to double the output in a proposed second phase. The mills were to produce rods and bars from billets supplied by the Delta Steel Company.

Unfortunately as earlier indicated, Delta steel has been unable to produce enough billets for its own rolling mills because of the dearth of working capital and inadequacy of raw materials and spare parts. Consequently the billet quantities delivered to the inland rolling mills were far short of the orders of the mills and this impacted negatively on the capacity utilisation of the rolling mills.

Table 5 shows, for example, the billet supply situation in the first four years of existence of the Oshogbo Steel rolling mill. By 1985 local supply was already being subsidized by import.

Year	Planned Tonnes	Supply (PS)	Actual Supply (AS) Tonnes	(AS/PS)%	Remarks
1983	210,000		14,000	6.7	
1984	210,000		24,000	11.4	
1985	210,000		38,000	18.1	20,000 Tonnes imported
1986	210,000		18,000	8.6	20,000 Tonnes imported

Table 5: Billet supply to Oshogbo Rolling mills from DSC

Table 6 shows the billet supply situation of the Jos Steel rolling mill between 1987 and 1991.

Year	Planned Supply (Tonnes)	Actual supply (Tonnes)	(Actual/plan)%
1987	210,000	22,366	10.7
1988	210,000	20,749	9.9
1989	210,000	18,860	9.0
1990	210,000	20,815	10.4
1991 (Jan-June)	105,000	7,884	7.5

Table 6: Billet supply to Jos Rolling Mills from DSC

From the foregoing data, Delta Steel barely supplied up to 10% of the billet supply needs of the inland rolling mills. The mills resorted to importation from abroad but soon ran into difficulty with import financing because of acute underfunding.

Table 7 shows the capacity utilisation in the three inland rolling mills in ten years between 1986 and 1995.

Year	Capacity Utilisation (%)		
	Jos	Katsina	Oshogbo
1986	12.40	31.2	15.4
1987	9.72	15.2	16.2
1988	8.43	15.6	7.9
1989	9.15	11.5	9.3
1990	9.52	9.1	8.8
1991	5.40	5.4	9.5
1992	7.30	4.8	11.1
1993	2.80	3.1	4.8
1994	4.56	16.7	4.5
1995	6.30	7.4	5.6

Table 7: Capacity Utilisation in the Inland Rolling Mills.

The table shows an overall decline in capacity utilisation between 1986 and 1991. The plants attained the lowest capacity utilisation ever at the onset of the on-going political crisis in 1993. The 16.7% capacity utilisation attained at the Katsina rolling mill in 1994 was financed with a Japanese loan of \$4m, which the company utilised for billet procurement. One year later in 1995 the company was back in the woods like the others.

PRIVATE WORKING INDUSTRY

The private metal working industries are involved in the rolling of rods, plates, sheets and various forms, extrusion of all sorts of sectional profiles and forging of high strength alloy components. Other working methods include sheet metal forming, wire, rod, tube and deep drawing and metal spinning.

The private rolling mills currently manufacture constructional mild steel rods and aluminium sheets. These plants satisfy only about 15% of the market demand for their products. The foregoing industry which traditionally produces tough high alloy machine components has hardly taken off the ground. It is currently comprised of a few

shops which form heads of long screwed bars for the production of bolts and cold-head wire rods for the manufacture of wire nails. Such high-strength components as spiders, connecting rods, camshafts, crankshafts, gear blank and cams for the automotive industry are not produced partly because of high capital outlay and partly because of lack of local production of alloy steel. If we must produce these important engine components, then, the public steel plants (Aladja and Ajaokuta) should be equipped to produce various grades of alloy steel.

In the metal drawing industry, ferrous and non-ferrous steel are drawn for the manufacture of nails, bolts, and screws and wire meshes for the agricultural industry. Flat sheets having high R-value and great resistance to thinning are deep drawn while some are spun to produce cones, hemispheres and straight-sided cylinders. Explosive forming is the newest method by which metal sheets are formed into difficult shapes.

FOUNDRY

Judging by the sheer volume of components produced by it and the wide variety of its products, foundry is easily the most versatile of the forming processes. It is also the one process that readily lends itself to wide private participation as capital outlay particularly for small family jobbing foundries are quite moderate. India owes her famed enormous forming capacity to her numerous family foundries.

The Nigerian foundry industry has for many years been limited to a few cupola furnaces and a handful of tilting type crucible furnaces. A few billet casting facilities are now available up and down the country. The newer foundries which may be found mostly in Lagos, Kano and Anambra States are predominantly small or medium-sized units geared primarily towards the production of cast iron pipes for urban water distribution and non-ferrous machine parts and fittings. A few of these foundries have acquired tremendous technical expertise over the years and are, therefore, capable of producing a wide variety of intricate castings.

Among others, the following have been identified as constraints to foundry development in Nigeria.

- a. high cost of land acquisition and of building
- b. insufficiency of experienced and skilled labour force.
- c. preference of multi-nationals for high-cost imported components at the expense of local manufacture
- d. import duty regimes which encourage importation of finished foundry products rather than the raw materials from which the same products may be locally manufactured.
- e. rapid and constant change of designs of cast components in vehicle assembly plants.
- f. Absence of strong local institution possessing advanced foundry technological know-how to solve industrial problems and provide the spring-board for developing substitutes for imported technology in such vital areas as
 - (i) mass production facilities
 - (ii) quality assurance and
 - (iii) new product development
- g. inadequacy of educational and training facilities for foundry tradesmen and technicians.
- h. dearth of advanced technological manpower and know-how in foundry technology
- i. inadequate infrastructural facilities.

RECOMMENDATIONS

The steel industry, we must accept is an important pillar on which national development must stand. In a paper we presented⁽²¹⁾ in 1980 to a seminar of the Nigerian Army corps of Electrical and Mechanical Engineers, we counseled against making a discouraging start to iron and steel development. Unfortunately the advice was not heeded; the nation bit much more than she could chew by embarking on too many projects at the same time. The result is that the Ajaokuta steel plant has not been completed and the Delta Steel plant and the inland rolling mills which have long been commissioned are unable to function effectively because of inadequate funding. Disillusioned staff are contin-

ually leaving for greener pastures at home and abroad while installed machinery and equipment are either rotting away or are being vandalized and relation to our current national economic standing that widespread misgivings have been expressed as to the wisdom of continuing with the projects.

I hold the view that because the nation has a tremendous lot to gain from the steel development programme, the only option open to us is to go ahead with renewed vigour and sincerity of purpose to implement the projects to conclusion. Wastes should be checked and corruption should be estemmed. No country has ever been adjudged great by whatever yardstick national greatness is measured, that has not achieved a reasonable measure of success in iron and steel processing. The following are our specific recommendations on the various aspects of iron and steel processing.

THE INTEGRATED STEEL PLANTS

The ownership structure of steel plants is very important in determining their prospects. This is the more so in developing economies where bureaucratic intervention is frequent and decisions are informed more by political than technical considerations. Most plants are owned privately in the developed nations of North America, Japan and Northern Europe. And except for the Hylsa steel company in Mexico and the Tata steel company of India, most steel plants in the developing world are publicly owned.

The persistent call for the privatization of the steel plants has been partly informed by the corruption and inefficiency that have characterized the running of similar public corporations and companies like NEPA, NITEL, NIPOST, NNPC, NRC, Nigeria Airways etc and partly by the seeming lack of commitment of government to provide the necessary resources and infrastructures needed for the steel plants to survive and flourish. But whereas privatization of the many ailing parastatals will be quite easy because of the prospect of high and quick return on private investment in them, the situation in the steel sector is completely different. Return on investment in steel production is normally moderate and cannot be high enough to encourage or stimulate private sector participation. Plant profitability can only be guaranteed in the long rather than in the short run.

If the share price movements in the Nigerian stock market are anything to go by, then the average Nigerian investor reckons more with the short rather than the long run. They invest in stocks that will yield quick and high return on investment. The steel sector cannot therefore, hold any inspiring promise for such investors. If we now discount the possibility of selling off the plants to foreign investors on the grounds of national pride, then the two integrated steel plants (Aladja Ajaokuta) must continue to be publicly owned.

In the circumstance, a new beginning is imperative if the plants must not become a permanent sink for public funds. The following are the minimum requirements that must be satisfied for the integrated steel plants to run satisfactorily;

1. The construction of all the plants must be completed and defective machines and equipment must be refurbished or rehabilitated. In particular, the outstanding 2% works on Ajaokuta should be completed and the flat steel project should be continued.
2. The high-tension (330KV) power link between Benin and Ajaokuta should be constructed to provide steady power supply to the Ajaokuta steel works. The captive thermal plant should also be re-activated.
3. Sufficient funds must be provided for the procurement of necessary spares and raw materials.
4. The current costs of importing specialized materials such as graphite electrodes, ferro-alloys, coke etc are far too high. Import duty concessions should be granted the plants for a limited period of 5 years while efforts towards local production of the materials should be intensified.
5. Energy costs (electricity and gas) to the steel companies are too high. The current NEPA tariff to the industry for instance is N2.150 per KWh. At this rate, the cost of electricity constitutes 13% of the production cost of Nigerian Steel. The world average is between 2½% and 5%.
6. Transportation of raw materials to the plants and the evacuation of finished products to the distribution centres should be made more efficient in order to reduce costs. These twin objectives can only be realized if the internal raw materials sources (e.g. Itakpe ore field) are linked

effectively by rail and, or water to the two primary steel plants. Road transportation as currently relied on is inefficient, costly and even dangerous to other road users.

7. High turnover of top-quality personnel should be stemmed. This can be done by increasing pay, improving conditions of service and by linking promotion to performance only. Quota should normally not be a criterion for employment but if it must be given expression for whatever reason, then it should be limited to the points of entry. Performance on the job should henceforth be the only criterion for advancement particularly to the very top.

8. Because of the specialized nature of the steel industry, the chief executives of integrated steel plants should be engineers who are highly qualified and experienced in the iron and steel field. The avoidable mistake of appointing misfits as the Chief executives of integrated steel plants as happened during the second republic should never again be repeated. Such unsuitable Chief executives cannot provide the leadership to inspire confidence, elicit loyalty and enhance corporate performance. Often they are a harbinger of division and perfidy in the labour force and a veritable source of industrial disharmony. Followership can only be responsive when the leadership is competent, confident and therefore respectable.

9. Involvement of the supervising ministries should be limited to enunciation of public policy on iron and steel. The type of interference in the day-to-day running of the plants which allows the ministry of iron and steel to fix the price of steel products should be discontinued. Product pricing should be based on costs and market indices and the discretion of management only.

THE INLAND ROLLING MILLS

Rolling mills are remarkably smaller in size, scope and investment potential than integrated steel plants. Even a fledging private sector like ours will have little difficulty running them efficiently. Indeed, the Nigerian private sector has acquired a considerable experience in the running of some twenty steel and aluminium rolling mills in various parts of the country. As no strategic interest will be served

by public ownership of the three stand-alone rolling mills, the reasonable thing to do is to privatize them. This will enable government to concentrate her resources on the development of the primary steel plant, which have been acknowledged as a sine-qua-non for national industrial development.

In the meantime there is a crying need to put to profitable use the heavy investments in the inland rolling mills. Various plants and machinery need be rehabilitated or refurbished and funds need be provided for capitalization and procurement of spare parts and raw materials. The private sector finance of production which some of the rolling mills experimented within the last two years appears to us to have a credible chance of success if some refundable seed money is provided by government to order raw stocks ahead of distributors' or dealers' orders. In the private-sector financed production arrangement, agreement is reached between the plant authorities and the dealer for the production of a specific quantity of rolled products. The customer orders the raw materials for processing and takes a percentage of the rolled product thus allowing the mill to sell the balance to cover expenses and make some profit.

FOUNDRY

Foundries, as we noted earlier, are ventures in which mass participation is most feasible because of the moderate investment required to set up small plants. Big foundries may produce scores of tons of cast products in a day while some may be so small as to produce no more than 5 tons of castings in a month. The latter category are small family ventures referred to as jobbing foundries. These outfits often specialize in the manufacture of single small-sized products. Advantages derivable from the establishment of a large number of small-scale foundries include

- a. Provision of a large number of private jobs.
- b. Dispersal of technical expertise.
- c. Availability of a wide variety of parts and components.
- d. Specialization in specific product manufacture and
- e. Healthy technical competitions that often result in the enhancement of product quality.

The current growth rate of the foundry industry in Nigeria is very poor. Besides the more established ones like the Nigerian Foundries limited which specialize in an assortment of cast iron products for the construction and water processing industries, most of the others are fighting a losing battle against unfair import duty regimes that make the importation of finished castings more attractive than the raw materials from which the same products could be locally manufactured. The effect is that the imported product is often cheaper than the local ones thus leaving the local entrepreneur with large unsold stock levels giving rise to loss in revenue and the concomitant need to curtail production and lay-off staff.

This is very unfortunate as Nigeria has a great potential to reap enormous benefits from a virile foundry industry. Nigeria's requirements for cast metals are, for instance, more than 200,000 tons per annum. Potential demand in the future is also estimated to be up to four times this quantity. And if the railway system is reactivated and tool and press shops are established, the demand could still be more.

If we must take advantage of the prospects offered by the foundry industry, concerted efforts should be made to see that the current negative trends in the industry are reversed. It is unthinkable, for instance, that many foundry technicians that are ordinarily in very short supply in the industry are unemployed because of diminishing activity in the foundry sector which ought to have been a major beneficiary of the erstwhile structural adjustment programme (SAP).

Raw Materials Costs

Import duties payable on all categories of foundry equipment and machinery and such raw material inputs as pig iron and Ferro alloys should be drastically reduced while duties payable on imported foundry products should be reviewed upward to a level that will make the locally produced castings reasonably competitive.

Scrap Metals

Scrap metals, a crucial raw material in foundry practices is a volatile asset which a long lull in manufacturing, as is currently being experienced in Nigeria, may render quite difficult to replenish. Therefore, efforts should be made to retain whatever level of scrap

metals is internally generated for the nation's foundry industry. A total ban on scrap metal export is indeed appropriate in the circumstance.

Energy Costs

The point was made in our discussion of the primary steel plants that energy (electricity and gas) costs to the plants were prohibitive. The same argument applies to the foundry industry. These rates should be reviewed downwards.

Education and Training

Lack of technical know-how was identified as one of the constraints to foundry development in Nigeria. At the moment only the technical colleges based in Enugu, Abeokuta and Ughelli run courses and are equipped to train craftsmen in foundry technology. Kwara polytechnic Ilorin and the Federal Polytechnic Idah are the only polytechnics running courses for foundry technicians and technologists. If the envisaged rapid development of the foundry industry is to be realised, then almost all the technical colleges currently available should train foundry craftsmen and at least one quarter of all existing polytechnics and colleges of technology should train foundry technicians and technologists.

ACKNOWLEDGMENT

Mr. Vice Chancellor, Distinguished guests, Ladies and gentlemen, I should not conclude this Lecture without paying tribute to those who have made significant contributions to my intellectual and professional development.

In this regard, the prime of place must be reserved for my parents, Alhaji Raji Asuni and Alhaja Halimat Shadia who were ready to pay any price for the education of their children. They are unavoidably absent today because they have died. May their souls rest in perfect peace. (Amen).

Professor V.A. Oyenuga of the University of Ibadan was the first professor Isonyin produced. As special guest of honour at our end-of-year concert at our primary school, Emmanuel School Isonyin, in December 1955, he delivered a most inspiring speech which left an indelible mark on my young mind. I was enamoured by his charisma, style and learning that I wished I could be like him. As fate would have it, I became the second professor Isonyin ever produced.

Mathematics and Physics, as we all know, are the main requirements for admission into engineering degree programmes. Mr. A.S. Odutola, the former principal of Adeola Odutola College Ijebu-Ode and later General Manager of Adebowale Electrical company Limited Lagos, was that outstanding teacher whose profound understanding of the subjects and elegant style of presentation made mathematics and physics such delightful subjects to learn in Ijebu Muslim College Ijebu-Ode of old. He made tremendous impact on my love for the subjects.

The line between success and failure is quite thin. When at the beginning of my career in academics, it appeared it would be impossible to make any meaningful contribution because of the absence of state-of-the-art research equipment, the like of which we all worked with abroad, and one was contemplating leaving the system, Professor J.C. Wright formerly of the University of Aston Birmingham and later director Steel Castings Research and Trade Association Sheffield, and Dr. J.L. Aston, formerly of the University of Aston advised that meaningful contribution could be made by a researcher if he concentrated on fundamental research into the problems of the community in which he lived. This advice largely

informed my research focus and has been very rewarding.

The cordial relationship I have enjoyed with the academic staff of my department and indeed the entire faculty has helped in no small way in facilitating my work. However, special mention needs to be made of those colleagues with whom I worked closely over the years on Materials Engineering. The late Dr. Jibade Olubode was a good leader of men. He was forthright, humane and courageous. Dr. Adesegun Aderibigbe was smart, boisterous and inquisitive. The late Dr. Patrick Anagbo was quick-witted, confident and unassuming.

Professor Olakunle Adepoju possessed a very fertile mind. His understanding of issues was always robust, his interpretation of experimental results elegant. Professor Adepoju unfortunately died a few years after giving an inaugural lecture he curiously titled "Metals: Dust to Dust". May the souls of all the departed colleagues rest in perfect peace (Amen).

Finally I wish to thank the almighty God for giving me such a wonderful family. My brothers, sisters and cousins were always ready to give a helping hand to alleviate the burden of what many regard as a thankless job. My children have always been friendly, considerate, level headed, unselfish, good mannered and decent. They have consequently contributed immensely in giving me the necessary peace of mind to face my primary assignments of teaching and research. It is indeed a great joy for me to see them growing into such promising young citizens who strongly believe in merit.

And last but not the least I give thanks to my wife of 27 years Titilayo Omokunbi for her understanding, love and support. Titilayo is a doting mother of our children and a most faithful and loyal wife of her husband. She possesses an uncommon strength of character that makes it remarkably easy for her to cope with any situation that arose in all our long years of marriage. To our nuclear family, she is a great tower of strength. May it please God to grant her good health to reap the fruits of her labour (Amen).

I thank you all for listening to me.

Thank you.
Professor S.A. Balogun
13th August, 1997

REFERENCES

1. R.F. Tylecote
A History of Metallurgy
The metal society 1976.
2. O.T. Adepoju
Metals: Dust to Dust
Inaugural Lecture Federal University
Of Technology Akure 1989.
3. S.A. Balogun, J.A. Olubode & D.A. Aderibigbe
Working Properties of Some Nigerian Synthetic
Moulding Sands
Nig. Jou. Eng. & Tech vol. 3, Nos. 1 & 2, 1980 (89-97)
4. S.A. Balogun & O.T. Adepoju
Effect of Some Additives on the Moulding Sand
Nig. Jou. Eng. & Tech. 1983
5. O.T. Adepoju & S.A. Balogun
Effect of Sand Grain Size and Texture
On Some Properties of Cast Aluminium
The Nigerian Engineer, vol. 18, no 4, 1984
6. O.T. Adepoju & S.A. Balogun
Effect of Mould Material on the Mechanical
Properties of Some Binary Aluminium Alloys
Nig. Jou. Of Eng. 1988.
7. O.T. Adepoju & S.A. Balogun
Melt Vibration Effects On The Texture and Mechanical
Properties of Aluminium and leaded Gun-Metal
The Nig. Engineer vol. 17, no 4, 1982, (119-124).
8. O.T. Adepoju, D.U.I. Ogo & S.A. Balogun
Effect of raw frequency vibration on the cast structure
and Mechanical Properties of basis brass and free-cutting
brass.
The Nigeria Engineer, Vol. 24, No 3, 1989 (65-78)

9. S.A. Balogun & O.T. Adepoju
Influence of Alloy Composition and Vibration on Ultra-
Sound Attenuation in Some Austenitic Ateels.
Trans. Indian Institute of Metal, vol. 39, no 4, 1986 (380-
388).
10. S.A. Balogun
Plane Strain Fracture Toughness of a $\frac{1}{2}\%Cr-\frac{1}{2}\%Mo -$
 $\frac{1}{4}\%V$, Cast Steel
Trans, Inst. of Metals, vol. 32, no 5, Oct. 1979, (374-378)
11. J.A. Shey, P.W. Wallace and F. Shunk
Metal Flow in Closed Die Press Forging of Steel
IITRI Research Report to American Iron and Steel Institute
1964.
12. S. A. Balogun
Influence of Flash Dimensions on Cavity Press Forging
Load
Metals Technology, vol. 1, pt7, July 1974 (320-324).
13. S. A. Balogun
Relevant Factors in Cavity Press Die and Design
Metals Technology, vol. 1, pt.11, Nov 1974 (501-505)
14. S. A. Balogun
A simulation of Die Stressing in Cavity Press Forging
Trans Indian Institute of Metals vol. 32, No.2, April 1979
(134-138).
15. S. A. Balogun and O.T. Adepoju
Effect of Welding on the Fracture Toughness of a Struc-
tural Steel Nig. Jou. of Eng. & Tech, 1984. Vol. 8, No.1,
1985 (16-24)
16. F.O. Abati-Sobulo
An Investigation of a Nut Crusher Failure
Department of Mechanical Engineering Project May, 1976.
17. Consultative Committee on Federal Government steel
Companies
The Nigerian (public) Steel Sector - Whither To?

- A Blue Print for the Optimal Operation, Sustenance and Survival of the Public Steel Industry. (Jan. 1997)
18. B. Oyelaran-Oyeyinka
The Steel Industry in Nigeria
Caltop Publications (Nig.) Ltd. (1994)
 19. Oshogbo steel rolling Co. Ltd.
Restructuring of the steel sector with respect to Oshogbo Steel Rolling Company limited
Report submitted to TCPC 16th December 1993
 20. M. A. Ogegbo and B.U.N. Igwe
Policies and Strategies for the development of a viable iron and steel Industry in Nigeria
Proceedings Annual conference Nigeria society of Engineers, Kano, 1984
 21. S. A. Balogun
Future Implication of iron & steel Complex to Nigeria's technology development
Proceedings Nigerian Army Electrical/Mechanical Engineering seminar, Lagos
April, 1980
 22. B. U. Igwe
Nigerian steel policy and economics by the year 200
Proceedings, 10th National conference, Nigerian Metallurgical society, NIPSS
Kuru June, 1988
 23. O. O. Mailafia
International perspective on the Iron and steel Industry
Proceedings, 10th National conference, Nigerian Metallurgical society, NIPSS
Kuru, June 1988
 24. W. I. A. Aderonpe
The role of Research and Development in the steel sector
Proceedings, 10th National conference, Nigerian Metallurgical society, NIPSS
Kuru, June 1988

25. P. U. Umunnakwe
Prospects for the delivery of iron ore to the Nigerian steel Industry
Proceedings, 10th National conference, Nigerian Metallurgical society, NIPSS
Kuru, June 1988
26. S. A. Balogun
Copy Technology as vehicle for Industrial development
Annual Foundation Lecture
Federal University of Technology Akure (1989)
27. National Committee on Foundry Development
Strategies for the development of foundry Industry in Nigeria
Federal Ministry of Science and Technology (1986).

