DESIGN AND PERFORMANCE EVALUATION OF A FORGE SUITABLE FOR METAL FORGING IN THE METALLURGICAL WORKSHOP IN THE DEPARTMENT OF MATERIALS AND METALLURGICAL ENGINEERING

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CERTIFICATION

I hereby certify that this project work "DESIGN AND PERFORMANCE EVALUATION OF A FORGE SUITABLE FOR METAL FORGING AT THE METALLURGY WORKSHOP OF THE FACULTY OF ENGINEERING was carried out by OIGIANGBE HARRISON EHIABHI, OKOJIE DANIEL, OSALUKA CHINONSO ISAAC, OSAMWONYI OSADEBAMWEN AND OYALUNA MICHAEL with matriculation numbers ENG1905558, ENG1905559, ENG1905560, ENG1905561, ENG1905563 respectively in the department of Materials and Metallurgical Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

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DEDICATION

This project is dedicated to the Almighty God, whose sure grace and profound mercy have brought me to this point, throughout my years of study at the University of Benin.

ACKNOWLEDGEMENT

I am immensely grateful to the Almighty God who has sustained me throughout my years at the University of Benin. I would like to express my sincere appreciation to everyone who has contributed to the progress of this project thus far.

I extend my heartfelt gratitude to my project supervisor, Engr. Dr. Wilfred Irogue, for his valuable ideas and unwavering dedication throughout the course of this project. I also want to thank the Head of Department Dr. U.G. Uneroh and all other lecturers and staff of the Department of Materials and Metallurgical Engineering for their guidance, mentorship, and overall assistance throughout my course of study.

Finally, my heartfelt thanks and appreciation goes to my family for their love, moral support, and financial assistance. May God continue to bless you all abundantly

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ABSTRACT

The aim of this research is to design, fabricate a forge equipment and thereafter carry out performance evaluation of an improved forge facility suitable for use in blacksmithing at the metallurgy laboratory of the University of Benin. .

This project aims to build the first forge facility in UNIBEN's Metallurgical and Materials Engineering department using local materials. It will provide hands-on learning for students and staff, bridging the gap between theory and practice.

The methodology employed in this study involves identifying problems and inefficiencies in a traditional forge, Review existing forge designs, their strengths, and weaknesses, Creation of a CAD model of an improved forge, Fabrication of the forge with a solar-powered forced draft for better airflow and combustion, Running of experiments to evaluate efficiency and effectiveness and Analysis of the results and provide recommendations for further improvements.

From the results of the study,some observations were made that increasing the oxygen supply with the M5 blower (forced draft) improved combustion efficiency. More charcoal led to higher forge temperatures, reaching 938°C with 600g of fuel.

With better combustion, aluminum softened faster, reducing the time needed to reach its forging temperature (300–400°C) from 7 minutes to just 4. In general, using more biomass resulted in higher temperatures and shorter heating times.

Overall, this study contributes to the development an affordable forge facility that can be locally produced and used for forge operations in the department of Materials and Metallurgical Engineering and Nigeria by extension for industrial and research applications.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The need to make work easier and safer to execute has immensely contributed to the development of many working tools. Starting from crude elements, man's quest for more efficient tools gave rise to the to the metal age which met societal needs along with advances in technology (Adebayo and Oke, 2018). Through the ages, the materials and quality of man's working tools increased. One of such tools commonly used today which has gotten its improvement from its crude forms is the metal forge. (Oke & Aderoba, 2000). A forge is a hearth used for forging. The term forge may also refer to the workplace of a blacksmith. The forge is a site at which metal is heated and shaped (Bealer, 1996). The process of forging as a manufacturing process involves the shaping of metal using localized compressive forces. A crude form of forging process is shown in Plate 1.1.

Plate 1.1 Covington and sons 2019

The process involves delivering blows with a hammer or a die and it is performed at various temperatures. Forging has been practiced by smiths for over time. A blacksmith is a metalsmith who creates objects from wrought iron or steel by forging the metal, using tools such as hammer, heat treatment bath, furnaces (RMRDC, 2007). The traditional products were kitchen ware, hardware, edged weapons like cutlass and knife, jewelleries and many hand tools (Oyenenye, 1984). However, following the modern times industrial revolution, forged parts are now widely used in mechanisms and machines. Mechanization arising from the industrial revolution has made forging a global industry in present day (Davis, 2016). Crude blacksmithing process remains old-fashioned, very simple and rudimentary that it is hardly employed as a viable means of commercial production of metal wares in Nigeria (Mahendra G, Nilesh). However, the improved process has brought about the production of many domestic and industrial products such as pails, cooking utensils, basins, keys, bolts and nuts, hammerheads household implements and weapons (Ajiboye and Adeyemi, 2003). A typical modern-day forge is shown in Plate 1.2.

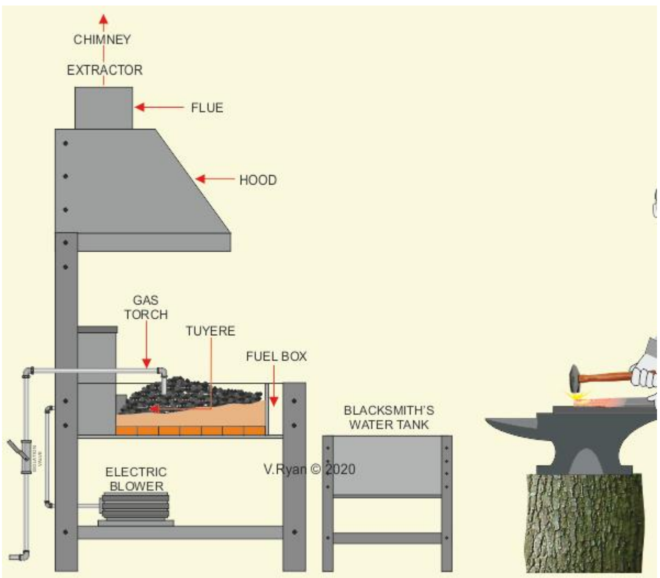


Plate 1.2 Forge Facility.

The forge product of blacksmithing is also very important and highly demanded by those in the construction industries. The modern-day forge being a significant tool for metal working process in metallurgy is unfortunately not available in many places today like Igun street of Benin City where blacksmithing is prevalent. They still rely on the crude methods. The University of Benin metallurgy workshop and laboratory is not also left out of this anomaly as it is currently not having a practical forge facility that can be used for industry and research purpose forging. Besides this, few available forges investigated within sight in Benin still rely on crude designs and power sources, hence the pertinence to develop a forge with improved power and heat sources. The aforementioned reasons have motivated the need to embark on this research as it will fill the gap of teaching and practical application if a forge is developed and domiciled at the metallurgy department of the University of Benin for teaching, learning, research and industrial purposes.

1.2 Statement of the Problem

The forge for blacksmithing is a significant facility for metal working such as shaping and sizing. It has become a huge industry practice over the years from its earlier crude forms. Unfortunately, many blacksmiths in in Nigeria today still rely of the crude models for forging such as relying on bellows and manual farming for enhanced heat as well as the use of coal which is environmentally unfriendly when not properly combusted and exhausted. The development of indigenous technology for developing small-scale industry in which blacksmith shop is included is important for fast development of complex technology industries (Okopo and Ezeadichie, 2003). In addition, the development of this type of small-scale manufacturing industries is the cornerstone of sustainable economic self-reliance (Oni and Lawal, 2003).

Furthermore, it is noteworthy that not a few forges have been seen around the Benin metropolis including the University metallurgy department where a forge is significantly required to teaching, research and practical purposes. These have all negated the call for industrial development in Nigeria and creates a gap between learning and practical application in an institution of leaning and research like the University of Benin. Owing to these shortcomings, the present research was necessitated to build an improved forge facility with some innovations suitable for forging and domiciled at the metallurgy laboratories of the University of Benin.

1.3 Aim and Objectives of the Research

1.3.1 Aim of the Research.

The aim of this research is to design, fabricate a forge equipment and thereafter carry out performance evaluation of an improved forge facility suitable for use in blacksmithing at the metallurgy laboratory of the University of Benin.

1.3.2 Objectives of the Research

The objectives of the research are to:

i. To source and incorporate local materials in the design and development if the forge facility.

ii. To bridge the gap between learning and practical application for students in the department of Materials and Metallurgical Engineering.

iii. By extension, this project would serve as a learning process for both students and staffs (both in the department and outside).

iv. To construct the first ever forge facility in the department of Metallurgical and Materials Engineering, University of Benin.

1.4 Significance of the Research

The understanding of the operational rudiments and design know how of a forge is critical to learning, hence this research will be a learning process for students and staff of the metallurgy department of the University of Benin. The improved design of a forge will foster the legislature for green working sustainable environment (Anyakoha,, 2012) with reduced environmental pollution. As part of local materials design and development, the present study will promote local use of technology and materials utilization as well the creation of jobs for Nigerians (Anamgba, and Azubuike, 2012). The study will underscore the decree of National Directorate for Employment (NDE) which was introduced in November 17, 1986 and launched on January 30, 1987 in the authority of Decree No.24 of 1989 which stipulated that unemployed school leavers were expected to acquire skills that they could work with if employed or take up self-employment. The (NDE) further expanded the programme to include the National Open Apprenticeship Scheme, National Youth Employment, and Skills Development Programme to enhance job creation. (Kanu, Njoku, and Nwachukwu, 2012). The study will not only be a source of providing the first forge facility for the modern day metallurgy department since its exclusive creation, it will also promote its periodical accreditation and close the gap between learning, research and practice.

1.5 **Methodology of the Research**

The method of approach for the execution of this project is as follows:

i. An initial study of a traditional forge to highlight its operational problems, challenges and anomalies.

ii. Conduction of an extensive literature review of available forge equipment, highlighting their areas of strength and their shortcomings.

iii. Develop a computer aided design (CAD) schematic of the improved forge facility

iv. Fabricate a forge with an improved renewable energy source incorporated with solar energy to power a forced draft to increase and control the supply of air stream into the fire to aid the combustion process.

v. Run tests to evaluate the performance of the forge.

vi. Provision of appropriate recommendation and conclusion from the test results.

CHAPTER TWO

LITERATURE REVIEW

2.1 Etymology: Early Forging Practice.

Blacksmithing is an ancient (Thomas-Ogubuji, 1989) indigenous technology which is the progenitor of various metal forming operations in use today and can be found in virtually all major culture of the world (Mai et al., 2022). The blacksmiths forging is a manufacturing process involving the shaping of a metal through hammering, pressing, sor rolling. The “black” in “blacksmith” refers to the black fire scales, which is a layer of oxides that form on the surface of the metal during heating and the origin of the “smith” originated from the proto-German “smithaz” meaning “skilled worker” (Online Etymology Dictionary, 2017). The word "smith" was also derived from an old word, "smite" (to hit). Thus, a blacksmith is a person who hits black metal (Bealer, 1996).

Traditionally, forging was performed by a smith using hammer and anvil, though introducing water power to the production and working of iron in the 12th century allowed the use of large trip hammers or power hammers that increased the amount and size of iron that could be produced and forged. Reference to steel, the forging process dates back well over 6,000 years, to 4000 BC and even earlier. It began in Mesopotamia (Joyce, 2002). The first metals forged here were gold, bronze and iron, which were used to produce tools, farm equipment (Sackey and Amoakohene, 1996), weapons and jewelry and other finished products (Parkinson, 2003). The advances in iron production that were made in the late 1700’s started what is now termed as the industrial revolution, and was responsible for the conversion of a manual labor-based production system to one of complete mechanization, cast and wrought iron was now being used to make these machines that would eventually cause demise of handcrafted work and would eventually signal and end of the road for traditional worker in iron. Henry Bessemer took out a patent to produce steel from pig iron in 1855, this could produce steel far more effectively and cheaper than it was produce wrought iron (Adebayo and Oke, 2017). The smith or forge has evolved over centuries to become a facility with engineered processes, production equipment, tooling, raw materials and products to meet the demands of modern industry. Though an old-fashioned process, the earlier blacksmithing method during the pre-colonial era is still practiced in Nigeria for the production of simple tools and devices primarily used for agricultural production (Adedoyin et al., 2011) such as holes, rakes, cutlasses, diggers, bolts and nuts (Otor, 2014, Catherine et al.,2014), spades, head pan and machetes. (Mahendra and Nilesh, 2014).

It is a common thing to see small scale metal workers like road side mechanics who are popularly called ojogun in communities who apply heat in working metals similar to the blacksmith practice. They virtually serve as an adjunct to roadside mechanics (Eboh et al., 1995). In modern times, industrial forging is done either with presses or with hammers powered by compressed air, electricity, hydraulics or steam which are now gradually replacing the crude methods of forging (Obikwelu, 1999, Ezeadichie, 2002)). These hammers may have reciprocating weights in the thousands of pounds. Smaller power hammers, 500 lb. (230 kg) or less reciprocating weight, and hydraulic presses are common in art smithies as well. Some steam hammers remain in use, but they became obsolete with the availability of the other, more convenient, power sources.

2.2 The Forging Process

The blacksmith forging is a process involving the shaping of metal using localized compressive forces. The blows are delivered with a hammer (often a power hammer) or a die. The forging processes can be grouped into three main classes: (Doege at al., 2010):

i. Drawn out forging: here the work piece length increases, its cross-section decreases

ii. Upset forging: the work piece length decreases, while its cross-section increases

iii. Squeezed in closed compression dies: in this type of forging, multidirectional flow is produced.

Virtually all forging processes can be performed at various temperatures. The classification of forging based on the working temperature is based on whether the metal temperature is above or below the recrystallization temperature (Doege et al., 2010). At temperatures above the material's recrystallization temperature, it is deemed as hot forging; if the temperature is below the material's recrystallization temperature but above 30% of the recrystallization temperature (on an absolute scale) it is deemed warm forging; if below 30% of the recrystallization temperature (usually room temperature) then it is deemed cold forging. The main advantage of hot forging is that it can be done more quickly and precisely, and as the metal is deformed work hardening effects are negated by the recrystallization process. Cold forging typically results in work hardening of the piece.

2.3. Effect of Heat Treatment of Metals in Forging

In forging, heat treatment processes are sometimes used before, during and after to enhance the metals properties, improve workability and achieve some desired mechanical characteristics. Here are some main heat treatment processes commonly associated with forging:

i. Pre-forge heat treatment

Annealing: This process is performed to soften the metal before forging, making it easier to deform. In more practical terms, it involves heating the required metal to a specific temperature, holding it there and then cooling it slowly. This in turn corrects any distortion in the microstructure, helping to reduce residual stresses and improve uniformity.

Normalizing: This is done before forging to create a uniform grain structure and reduce internal stresses in the raw material.

ii. Post-forge heat treatment

Quenching: Rapidly cooling the forging metal (in water, oil, or air) after heating to harden it by forming martensitic structures.

Tempering: Heating the quenched metal to a lower temperature to reduce brittleness while maintaining strength

Forging in a deeper view, also does some changes macroscopically to the work piece as it alters the inner structure (microstructure) of metals, thereby improving their mechanical properties and overall performance. Some key effects that forging has on a metal's inner structure include the followings;

i. Grain refinement: the forging process breaks up the coarse grain present in the metal, leading to a finer and more uniform grain structure, therefore increasing the materials strength, toughness and its resistance to fatigue.

ii. Elimination of porosity: forging compresses the metal, closing voids and gaps that may have existed in the raw material. This enhances the density and mechanical integrity

iii. Improved grain flow: during forging, the mechanical working aligns the grains along the flow of the material. This "grain flow" follows the shape of the forged part, providing better directional strength and resistance to stress fractures

2.4 Types of Forging

The various types of forging include the followings (Reliance Foundry, 2020).

a. **Drop forging**:

Drop forging process involves a hammer being raised and then dropped into the work piece to deform it according to the shape of the die. The drop forging is characterized by two forms which include

i. Open-die drop forging also known as smith forging; involves a hammer used in striking and deforming the work piece, which is placed on a stationary anvil. The dies (the surfaces that are in contact with the work piece) do not enclose the work piece, allowing it to flow except where contacted by the dies.

ii. Impression-die or closed-die forging; the metal is placed in a die resembling a mold, which is attached to an anvil. Usually, the hammer die is shaped as well. The hammer is then dropped on the work piece, causing the metal to flow and fill the die cavities.

b. **Press forging**

Press forging works by slowly applying a continuous pressure or force in rapid succession of milliseconds which differs from the near-instantaneous impact of drop-hammer forging. The press forging operation can be done either cold or hot. The main advantage of press forging, as compared to drop-hammer forging, is its ability to deform the complete work piece. Drop-hammer forging usually only deforms the surfaces of the work piece in contact with the hammer and anvil; the interior of the work piece will stay relatively un-deformed.

c. **Upset forging**

In upset forging, the diameter of the work piece is increased by compressing its length. Based on number of pieces produced, this is the most widely used forging process. A few examples of common parts produced using the upset forging process are engine valves, couplings, bolts, screws, and other fasteners. Upset forging is usually done in special high-speed machines called crank presses. The machines are usually set up to work in the horizontal plane, to facilitate the quick exchange of work pieces from one station to the next, but upsetting can also be done in a vertical crank press or a hydraulic press.

d. **Automatic hot forging**

The automatic hot forging process involves feeding mill-length steel bars into one end of the machine at room temperature and hot forged products emerge from the other end. The main advantages to this process are its high output rate and ability to accept low-cost materials. Little labor is required to operate the machinery.

e. **Net-shape and near-net-shape forging**

This is also known as precision forging. the final product from a precision forging needs little or no final machining. Cost savings are gained from the use of less material, and thus less scrap, the overall decrease in energy used, and the reduction or elimination of machining.

f. **Roll forging**

This is a process where round or flat bar stock is reduced in thickness and increased in length. It is basically performed using two cylindrical or semi-cylindrical rolls, each containing one or more shaped grooves. A heated bar is inserted into the rolls and when it hits a spot the rolls rotate and the bar is progressively shaped as it is rolled through the machine. The piece is then transferred to the next set of grooves or turned around and reinserted into the same grooves. This continues until the desired shape and size is achieved.

g. **Multidirectional forging**

Multidirectional forging is forming of a work piece in a single step in several directions. The multidirectional forming takes place through constructive measures of the tool. The vertical movement of the press ram is redirected using wedges which distributes and redirects the force of the forging press in horizontal directions (Behrens et al., 2014).

h. **Isothermal forging**

Isothermal forging is a process by which the materials and the die are heated to the same temperature. Adiabatic heating is used to assist in the deformation of the material, meaning the strain rates are highly controlled. This technique is commonly used for forging aluminum, which has a lower forging temperature than steels. Forging temperatures for aluminum are around 430 °C, while steels and super alloys can be 930 to 1,260 °C for hot forging of steel. Warm forging of steel temperatures is between 750–950 °C while Cold forging of steel temperatures at room conditions, is up to 150 °C due to the forming energy. Aluminum forging is performed at a temperature range between 350–550 °C. (Doege et al., 2010).

h. **Cold forging**

Without heating or applying heat source, near net shape forging is mostly achieved for such as slug, bar or billet. Aluminum is a common material that can be cold forged depending on final shape. Lubrication of the parts being formed is critical to increase the life of the mating dies.

i. **Induction forging**

Induction forging is based on the type of heating style used. Many of the forging processes can be used in conjunction with this heating method.

2.5 Forging Facility and Materials

The most common type of forging equipment is the hammer and anvil shown in Plates 2.1 and 2.2.

Plate 2.1 Hammer forging process.

Plate 2.2 AN Anvil for forging

The modern-day advanced forging facilities like the hydraulic powered forge shown in Plate 2.3 are still a replica of the basic principle of drop hammering on the anvil surface.

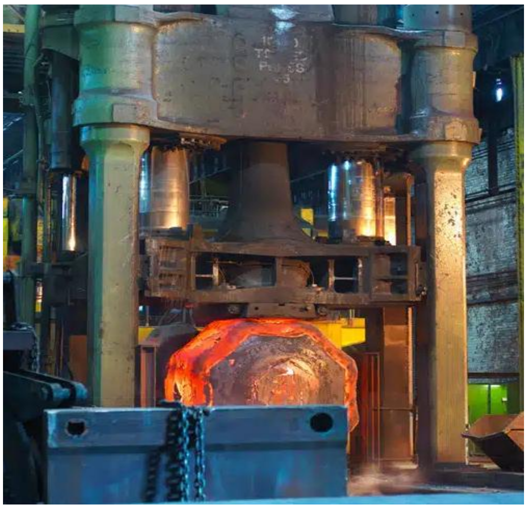


Plate 2.3 A hydraulic powered forge

A typical forge comprises of the heat source which can be charcoal, electrical or gas, an exhaust hood for smoke escape, pipe network for air flow, and a blower for generation of air. The function of the blower is to deliver a consistent air supply to the base of the fire to aid the combustion process (Robert, 2007). Supplying the fire with oxygen means that the fire can get to a temperature hot enough to manipulate and craft iron object without a consistent supply of oxygen. Hand forging' involves the use of an anvil and special hammers, chisels and swages. A 'drop forging machine' uses pneumatic or hydraulic pressure to compress hot metal blanks between a hammer.

2.6 Forging Process Machines and Accessories.

The forging process is carried out using a typical blacksmith forge which comprises of the following tools and accessories (Ebmpapst, 2017).

i. The forge stand

The forge stand is made of metal and it acts as the structural component of other components of the forge. Its geometrical dimensions will depend on the amount of work to be executed with it as well as the size and age of operators.

ii. Blower

A blower is used for forced draft of air (oxygen) to the furnace for enhanced combustion during the forging process. The blower can be manually or electrically operated. A typical electric blower is shown in Plate 2.4.

Plate 2.4 Air blower in a forge

iii. Furnace pot

The forge furnace pot shown in Plate 2.5 contains the fuel component and it is where the forged material is heated up to cherry red temperature. The firepot may be designed with a clay and fire bricks to increase the heating efficiency and at the same time retain more heat in the area. this helps to reduce the radiation effect of the heat exposure to the blacksmith as well as save on fuel consumption.

Plate 2.5 Forge pot

iv. Forge Air manifold (Y-Tuyere)

The two-air inlet channel manifold Y-shape mild steel tube shown in Plate 2.6 has an inlet air flange to which the blower is connected and another from which air goes into the furnace pot. The third (downward) outlet flange is where the ash residue is extracted.

Plate 2.6 Forge Tuyere

v. Heat exhaust hood

The forge heat exhaust hood shown in Plate 2.7 allows excess heat and ash powder to escape from the forge to the surrounding environment. It is often located above the forge pot as part of the forge structural stand.

Plate 2.7 Forge exhaust hood

vi. The Hammer and Anvil

During the forging process, the work piece is placed on the anvil, and the work piece gets shaped when it is struck with the hammer on it. The anvil and hammer combination use is shown in Plate 2.8.

Plate 2.8 Anvil and Hammer.

. In advanced industrial setup, shaping and hammering of metal may be mechanized using four basic types of impact application equipment which include

1. Drop hammers
2. Screw press actuated hammer
3. Crank press hammer
4. Hydraulic press hammer.

Forging hammers are classified as either broad or power hammer. The Working principle of these hammers is based on a potential energy that is converted to a kinetic energy and then to a deformation energy. Broad hammer machine depends on the force of gravity. This is one of the reasons why they are also referred to as the gravity drop hammers or drop hammers. They are commonly used for the impression die forging manufacturing process. These machines depend on the potential energy that is due to the force of gravity. This implies that, the magnitude of force will depend on the weight of the hammer and the height. In most cases, the height is typically less than 6 feet. This is one of the main reasons why it is referred to as the energy restricted machine. Depending on the design of forging hammer, they can strike between 60 and 150 blows/minute. However, this depends on both the capacity and the size of the hammer. Again, the die used in this forging process are expensive. Besides, metal can be subjected to thermal shock. This can affect the quality of final part.

Forging hammers have higher forging force. Unlike Broad hammers, the total force is due to steam/air pressure plus gravitational force. The pressure is an induced force during downward stroke which results in a higher acceleration. Again, the stem/air pressure can also be used to raise ram during the upstroke. Other parameters will still remain the same as in the case of broad hammers.

2.7 FORGING MATERIALS

A cross section of materials that can be forged include the following:

BRASS

Brass is one of the most popular alloys that can be forged. This is mainly due to the fact that it can be shaped to the desired shape easily. Brass is known for its good formability and high thermal properties (CFS, 2024). Before forging, heat treatment such as annealing is often performed so as to enhance its ductility and reduce hardness, making it easier to forge and shape.

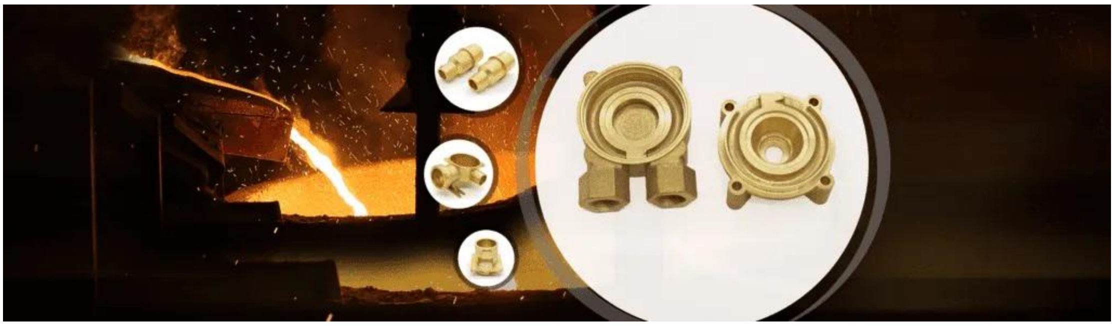


Plate 2.8 Brass sample

It is a copper alloy that offers a wide range of benefits and has been incorporated in a number of applications.

- Possible to achieve a high degree of dimensional precision.
- Easy to achieve zero draft forging. But not always practical in most circumstances.
- Forged brass parts have improved strength. That's why they are used for hydraulic pumps, some gears and bearings.
- Corrosion resistant, it makes them suitable for chemical processing industries.
- Pressure tight, hence, they are commonly used in high pressure liquid and gas handling. A number of brass forged parts include refrigeration components, pipe fittings, commercial valves, etc.
- Forged components have a porosity free structure.
- Easy clean and easy to achieve superior surface finish.

The forging brass, identified as C37700 is rated 100%. It is the most forgeable type. Others which contain 35% to 40% of zinc are rated at 90%.

STEEL

There are quite a number of alloy steel forging that are used in different manufacturing industries. Whichever type of steel being used, it is subjected to extreme temperatures (sometimes to its recrystallization point) before forging with the aim to correct any distortion in the grain structure so as to improve its machinability, reduce internal stresses present and improve its overall quality in the end. Some of the most popular alloys include the 4140, 4130 and 4340.

There are other types of steels with nearly the same chemical and physical properties. However, there are some variations based on the elements contained.

Plate 2.9 Steel sample

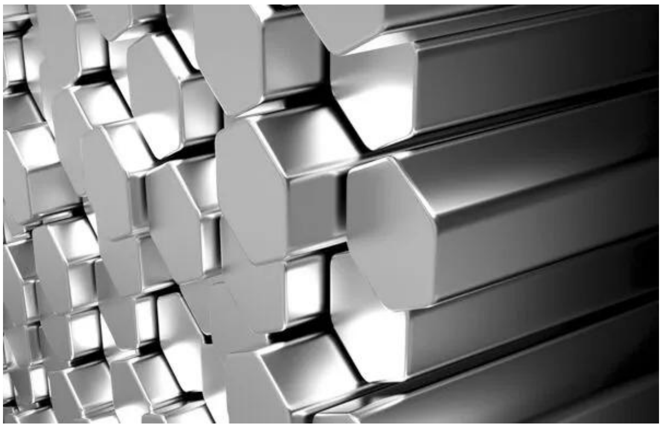
COPPER

Copper and its alloys used in a number of industrial applications. This is due to its excellent electrical and heat conductivity properties. It is known for its non-magnetic, corrosion resistance, machinability, ductility, malleability and wear resistance. Forged copper parts are a perfect choice in applications where there's higher temperatures and at a higher load. Again, the parts can withstand high stress without unexpected failures. In most cases, forged copper parts are highly recommended. (Bunty, 2019).

Plate 2.10 Copper sample

STAINLESS STEEL

Stainless steel, which is available in 304, 314, 316 and 403, can be open die forged into different shapes. There are about 200 grades of stainless steel to choose from. This leaves die casting companies with a wide range of options to choose from. In normal industrial setup, parts that can be obtained include: copper discs, shafts, rings, Plates. (Nickel, 2019)



ALUMINUM

Forging of aluminum is performed at a temperature range between 350–550 °C. Forging temperatures above 550 °C are too close to the solidus temperature of the alloys and lead in conjunction with varying effective strains to unfavorable work piece surfaces and potentially to a partial melting as well as fold formation (Ostermann, 2014). Forging temperatures below 350 °C reduce formability by increasing the yield stress, which can lead to unfilled dies, cracking at the work piece surface and increased die forces. (Stonis, 2011).

Plate 2.12 Aluminum sheet sample

2.8 ADVANTAGES AND DISADVANTAGES OF THE METAL FORGING PROCESS

Applying a compressive force at specific temperatures has both advantages and disadvantages. It is one of those manufacturing processes that depend on temperature. Ideally, the main advantages and disadvantages of the process can be discussed based on the type of the forging process. Whether it is hot forging or cold forging, the two processes are slightly different; however, they produce the same results.

In hot forging, the metal is heated to a temperature above the recrystallization temperature (Degarmo, 2019). A desirable compressive force is applied to manipulate metal to a desired shape. During this period, the metal is subjected to a number of strain hardening effects. The temperature will depend on the metal to be forged. For example:

- Copper alloys require between 710 and 800 degrees.
- Steel alloys require between 1100 and 1150 degrees.

- Aluminum alloys require between 350 and 520 degrees.

Advantages of hot forging (Farinaa, 2018)

i. The parts have increased ductility and strength; this makes them a perfect choice for most application
ii. Flexibility; hot forging is more flexible than cold forging. This is because customized parts can be manufactured easily.
iii. Superior surface finish; this allows for a number of finishing operations such as painting, coating or polishing (Rathi, 2014).
iv. High temperature removes any homogeneous substances. This is due to the increased diffusion.
v. There is a reduction in the pore size.

Disadvantages of hot forging

i. Hot forged parts tend to have less precise dimensional tolerance
ii. Grain structure of the final metal may vary. This may be due to the reaction between the material and the surrounding environment. (Kumar et al., 2022).
iii. Warping may occur during the cooling process; hence, the cooling should take place under controlled environment.
iv. There could be varied metal structure.

In cold forging, the metal is subjected to compressive forces at temperatures below the recrystallization temperature. This is actually the opposite of hot forging. Normally, it's the room temperature. The most common process that is used is the impression-die casting. It is a perfect choice for soft metals.

Advantages of cold forging (Sekhon et al., 2014)

i. Most cold forged parts do not require any secondary operations.
ii. It is cost effective and not labor intensive.

iii. Smooth surface finish due to less impurities.

iv. It’s a precise manufacturing process

Disadvantages of cold forging

i. Less ductile making them unappropriated for certain applications.

ii. There are chances of residual stress occurring. This because the strength of the material depends on the grain structure

iii. Requires powerful and heavy machinery.

iv. Surface of the metal must be cleaned before forging process starts.

2.9 Safety Considerations in Forging (Degarmo, 2019).

i. The use of personal protective equipment: By using heat resistant gloves, goggles, steel-toed boats and hearing equipment, one can prevent burns or any form of injury.

ii. Machine safety: Personnel operating should maintain the equipment, and follow safety rules to prevent accidents

iii. Fume and dust control: proper exhaust systems and ventilation must be provided to prevent future respiratory issues

iv. Use of hot handling materials: by using specialized tools and marking the hot areas, it can reduce burns and other fire related hazards.

2.10 Review of Related Literatures

A list of selected literatures has been reviewed as follows:

Hawryluk, et al., (2023). carried out research on the development of preliminary precision forging technology and concept for tools used to re-forge 60E1A6 profile needle rails with the use of numerical and physical modeling. The study examined the possibilities of applying numerical and physical modeling to the elaboration of technology and design of tools used in the hot forging of needle rails for railroad turnouts. A numerical model of a three-stage process for forging a needle from lead was built in order to develop a proper geometry of the tools' working impressions for physical modeling. Based on preliminary results of the force parameters, a decision was made to verify the numerical modeling at 1:4 scale due to forging force values as well as agreement of the numerical and physical modeling results, which was confirmed by the similar courses of forging forces and a comparison of the 3D scan image of the forged lead rail with the CAD model obtained from FEM. The final stage of the research was modeling an industrial forging process in order to determine the preliminary assumptions of the newly developed method of precision forging using a hydraulic press as well as preparing tools to re-forge a needle rail from the target material which was a 350HT steel with a 60E1A6 profile to the 60E1 profile used in railroad turnouts.

Mai et al (2022) carried out an assessment of local blacksmithing industry in Maiduguri, Borno state Nigeria. The study explored the necessity of finding out the challenges faced by the blacksmith industry in Maiduguri and suggested a possible way of integrating/updating them. The study considered the standardized interview technique where questionnaire designed and asked verbally in a face-to-face to gather the needed information. Training, capacity building and education on the safety related issues was highly recommended as part of the authors' recommendations.

Elenwo (2021) carried out a research study on showing blacksmithing as an alternative income earner to unemployed Nigerians and other parts of the world for sustainable development. The study was carried out with focus on Elele alimini blacksmithing. The aim of the study was to establish the usefulness of blacksmithing to mankind with the view of recommending the trade to the youths as a substitute for government and other employers' employment in Nigeria and other parts of the world. The findings were based on biographical survey of qualitative research methods and research questions which tested the objective of the study. It adopted the historical survey technique which relied heavily on primary and secondary source of data collection. It was ascertained that the value of blacksmithing to mankind was enormous. Therefore, blacksmithing to mankind was been established as a potential occupation in Nigeria and other parts of the world for sustainable development.

Adebayo and Oke (2018) developed a forging machine for improved blacksmithing in Nigeria. The aim of the research was to perform an investigation in the production processes and methods of operation of the blacksmith forging machine in six blacksmith shops in Nigeria. Qualitative study combined with a survey was used for the study design. the study was carried out in five states including Edo, Ondo, Osun, Ekiti and Oyo states in Nigeria. Investigation of the production processes was done using questionnaires which were administered to ninety people and they were grouped according to their ages in all the sample states. The mechanical and metallographic examination was carried out in engineering materials and development institute (EMDI) Ondo State, Nigeria. Samples of selected blacksmith products were machined into shapes and sizes suitable for the tests. The selected products were grounded using emery paper of grades 220, 320, 400 and rough polished on glycerol-lubricated silicon carbide paper. In evaluating the performance of the forging machine, three mild steels of length 177 mm each were heated and hammered by the machine to produce three chisels shape of 15 mm in diameter. The electric hammer consists of a flywheel of diameter 300 mm mounted on the motor shaft. The analysis of the questionnaire showed that young people do not go into the blacksmith business because of the stress involved and they are unable to forge the heated metals effectively. This is an indication that blacksmith may soon fade out if it is not modernized and mechanized to reduce the stress involved in the processes. The forging capability was 85Joules (energy at strike).

Daviz, (2016) carried out research on the design, construction, and evaluation of a gas forge. The purpose for building the propane forge was to replace an old charcoal forge in order to improve upon certain points of performance such as adjustability of heat, portability, and fuel cost by being able to run the forge for any amount of time with an easy on/off control. The design of the forge consisted of a steel pipe body insulated with ceramic fiber blanket, and was heated by a single atmospheric burner.

Edward (1995) built a homestead forge where he molded the forge with clay and stone with a bellow blower attached.

(Catherine et al., 2014) in their work on assessment of the Blacksmithing Industry in Ghana, looked at the different methods and tools of skill expertise of blacksmithing in Kumasi Ghana where different forge designs were used.

Kocanda (2013) conducted research on the developments and analysis of side forces in forging dies. Combined thermo-mechanical numerical analysis of some industrial hot forging processes with special attention to the side forces acting on die impressions was presented in the research. The author asserted that side forces caused an offset of the upper and lower dies which introduces geometrical inaccuracies into forgings or increased wear of some parts of die impression. There were examined forging processes for production of alloy steel turbine blade, medium alloyed steel valve lever and medium carbon steel bracket lever. Various modifications of impression shape and its positioning as well as changes in parting line have been were taken into account. The values of side forces differed considerably with all of the modifications. Some solutions for analyzed forging processes were suggested in order to minimize the side forces and their influence on geometrical inaccuracy of forgings.

Yamba et al (2017) carried out a research study on the re-design and manufacture of a mobile multi-blowing blacksmith forge. The authors asserted that, the problems in our localities about the blacksmith forge is that the forge is created by molding the firepot out of digging the ground which is not convenient to use, wastes a lot of charcoal (fuel) and is also static in nature. Therefore, a mobile multi-blowing blacksmith forge was re-designed by the authors to eradicate these problems and its performance was evaluated. The test results of the research showed that the forge was efficient in retaining heat much longer than the primitive once hence improving fuel efficiency by increasing income and also due to its lining, heat radiation was drastically reduced thereby providing much healthier environments for the blacksmith.

Oladimeji (2013) carried out research on the potentials of and the socio-economic benefits of blacksmithing production in promoting agricultural development and poverty alleviation in kwara state, Nigeria. The study examined the potentials and contribution of blacksmithing practices to household income and poverty alleviation in kwara State, Nigeria. Eighty blacksmith artisans were randomly selected in the sixteen LGAs of Kwara State for the study. Primary data was obtained with the aid of structured questionnaire and personal interview schedule to elicit information relevant to the study. Descriptive statistics, net income and OLS models were employed in the data analysis. The results revealed prospects of increased revenue generation to blacksmiths. The blacksmiths were at the edge of productive age with modal class of 48-57 years, low literacy rate and the bulk had subsidiary occupations to supplement their income. The average household size per smith was approximately 7 and mean daily income earned from production ranges from ₦500 to ₦950.The postulated explanatory variables explained 48.8% in the variations in income earned by blacksmiths.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

The materials and their respective functions required for the blacksmith forge development are shown in the Table 3.1.

Table 3.1 Materials required for the development of the solar thermal water heating system

S/N	Materials	Function
1	Personal computer	For CAD drafting and typesetting
2	Sheet metal	Use for the production of the exhaust hood and combustion chamber of the forge.
3	Structural steel	For construction of the forge structure.
4	Anvil	Metal block for impact hammering.
5	Hammer	For impact force on forged material.
6	Forced draft fan	Supply of air for combustion.
7	Ash tray	For removal of ash.
8	Air flow pipe	Route for combustion air supply.

3.2 Method

The systematic approach adopted for development of the forge facility is as follows:

3.2.1 Conceptualization

Various concepts of the forge are considered. Considering preliminary design considerations, two concepts meet the initial mark for potential consideration and onward production. A preferred concept will be selected amongst the two using a decision matrix. The two concepts considered based on specific design considerations a decision matrix include:

Concept One: Propane fired forge

This concept shown in Plate 3.1 rely on firing the combustion chamber with propane gas. The forge facility consists of a propane cylinder with nozzle and hose which is connected to a high heat resistant burner. The burner produces the hot flame for firing the metal work piece.

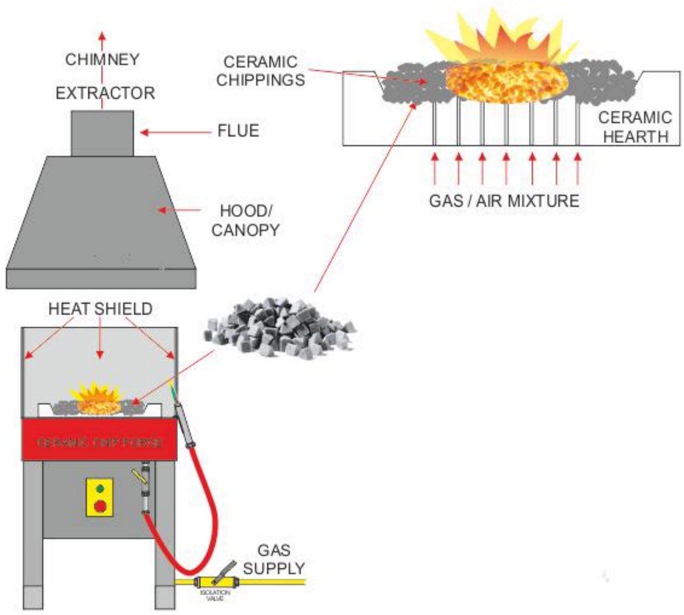


Plate 3.1 Propane fired blacksmith forge

Advantages of concept one

1. The major advantage of the propane fired forge is that it uses a natural gas with less emission and environmental pollution.

Disadvantages of concept one

1. Propane gas quite costly to acquire natural.
2. The heat value of propane (2524kJ/kg) may be low compared to other cheaper fuels like biomass

Concept Two: Biomass fired forge

This is shown in Plate 3.2. the biomass fired forge consist of a heat resistant crucible which has a melting point higher than that of the work piece metal. The crucible is connected to a forced draft fan which supplies the air required for combustion in the forge furnace. Biomass used in this case may be wood charcoal or other types of natural materials biomass.

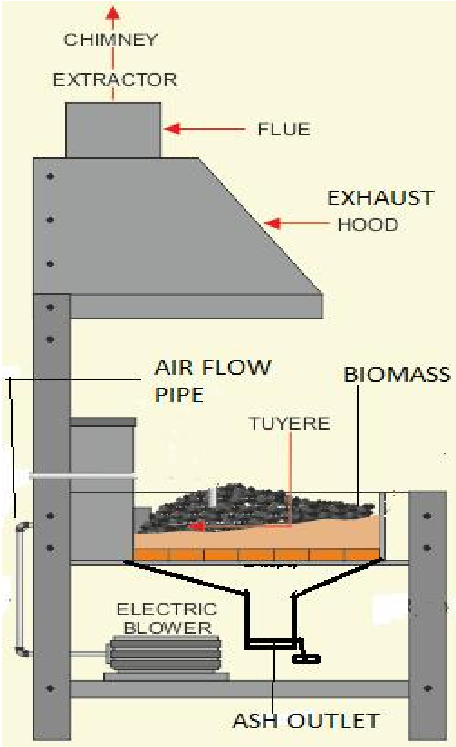


Plate 3.2 Biomass fired blacksmith forge

Advantages of concept two

1. Biomass such as coal is relatively cheap.
2. More refined biomass with less emission are now available.
3. Biomass can be re-used series of times before finally burning out to ashes.
4. It has high heating values within 32080kJ/kg.

Disadvantages of concept two

1. The legislature on zero emission inhibits inordinate use of biomass fuels.

3.2.3 Evaluation and selection of concept using decision matrix

The two concepts highlighted are reviewed based on specific design criteria and the most viable concept is selected using a decision matrix as shown in Table 3.2.

Table 3.2 Decision matrix for solar thermal water heating concept selection

S/N	Design Specification	Concept 1	Concept 2
1	Improved heating capacity	1	2
2	Environmental pollution	2	1
3	Energy use and conservation	1	2
4	Reliability for scaled up use	2	2
5	Cost of production and acquisition	1	2
	TOTAL	**7**	**9**

From the Table 3.2, it is observed that the concepts 2 has the highest weighted score based on the criteria considered, hence the concept 2 is adopted for development.

3.3 Detail Design

3.3.1 Energy requirement of forge

This is the amount of heat to be supplied by the forge and it is a function of the type of biomass fuel to be used. It can be determined based on the nature, softening temperature and amount of metal works piece to be heated inside the forge. The softening temperature of a forged metal is the temperature where the metal starts to soften significantly due to increased atomic vibration, allowing for easier deformation when impact force is applied. Typical metals and their thermal characteristics to be forged using the blacksmith forge are shown in the Table 3.3.

Table 3.3 Thermal characteristics of metals to be fired.

Metal	Softening temperature (°C)
Brass	0.42 – 0.44
Copper	800
Bronze	913
Nickel	(720-122) for its alloys
Steel	900 (may vary due to carbon content)
Aluminum	500

The amount of energy needed to cook food can be computed using the formula,

$$Q_n = \frac{M_f \times E_s}{T} \qquad (3.1)$$

where:

Q_n - energy required, Kcal/hr

M_f - mass of metal work piece

E_s - specific energy, KCal/kg

T – heating time (Osifo,2022)

The average energies for heating and forging of metals could be used to estimate the fuel consumption rate of the forge in Kcal/hr.

The type of biomass to be used capable of producing the required thermal softening temperature can be selected from varieties of available coal biomass some of which are listed in the Table 3.4.

Table 3.4: heating value (HV) of different coals. (Yohannes, 2011)

Coal grade	Heating value (kJ/kg)
Anthracite	30080
Semi anthracite	32084
Low volatile bituminous	33412
Medium volatile bituminous	32247
High volatile bituminous	(21319-30499)
Sub luminous	(20830-21319)
Lignite	16077

Considering the heating values of coal in Table 3.4, it is observed that they are higher the HV of propane and can suffice for use in the forge furnace.

3.3.2 Energy Input

This refers to the amount of fuel energy fed into the forge. It is computed as,

$$FCR = \frac{Q_n}{HV_f\, x g} \quad 3.2$$

Where:

FCR - fuel consumption rate, kg/hr

Q_n - heat energy needed, Kcal/hr

HV_f - heating value of fuel, Kcal/kg

x_g – forge furnace efficiency, %

Time to consume biomass

This refers to the total time required to completely gasify the biomass inside the furnace. Gasification is a thermal conversion process where carbonaceous materials such as wood coal is converted into gaseous product under influence of temperature and gasifying medium such as air at higher temperature (Zuberbuhler, 2005). The time for complete gasification include the time to ignite the biomass plus the time to completely burn out the biomass in the furnace. It is dependent on the density of the biomass (p), the volume of the furnace sphere (V), and the fuel(charcoal) consumption rate (FCR). This can be computed using the formula:

$$T = \frac{p \, x \, V}{FCR} \qquad 3.3$$

where:

T - time required to consume biomass, hr

Vr - volume of furnace sphere m^3

p - biomass density, kg/m^3

FCR - rate of consumption of charcoal, kg/hr.

Amount of Air Needed for Gasification

This refers to the rate of flow of air (AFR) needed to combust the biomass. It is also necessary in determining the size of the blower required for supplying oxygen to the coal inside the furnace. It is dependent on the rate of consumption of biomass (FCR), stoichiometric air/biomass (SA), and the recommended equivalence ratio (e) for gasifying the biomass. (0.4 for wood charcoal).

Mathematically, AFR can be computed as,

$$AFR = \frac{\varepsilon \, x \, FCR \, X \, SA}{pa} \qquad 3.4$$

where:

AFR - air flow rate, m^3/hr

e - equivalence ratio, 0.3 to 0.4

FCR - rate of consumption of biomass (wood charcoal), kg/hr

SA - stoichiometric air of biomass taken as 4.5 kg air per kg wood charcoal

ρa - air density, 1.25 kg/m^3

Superficial Air Velocity

This refers to the speed of the air flow in to the biomass bed. The velocity of air in the bed of biomass will cause channel formation, which may greatly affect combustion of the biomass.

The diameter of the air flow pipe and the airflow rate (AFR) determine the superficial velocity of air in the gasifier furnace. This can be computed as;

$$V_s = \frac{4AFR}{\pi D^2} \quad 3.5$$

where:

V_s - superficial gas velocity, m/s

AFR - air flow rate, m^3/hr

D - diameter of flow piper, (m)

Resistance to Airflow

This is the amount of resistance exerted by the fuel and by the char inside the furnace sphere. It also determines the requirement of a fan or a blower is needed for the furnace.

Total resistance needed for the fan or the blower can be computed as;

$$R_f = T_f \times Sr \quad (3.6)$$

where:

R_f - resistance of biomass equivalent to pressure of a column cm of H_2O

T_f - thickness of biomass column, m

Sr - specific resistance, cm of water/m of fuel

The specific pressure resistance of water per m depth of fuel can be read off in charts. Taking specific pressure resistance of 1 cm water per m depth of fuel.

Blower (fan) selection

The air volume flow rate (m^3/s) is dependent on the blade configuration of the blower. It is expressed as:

$$Q = A \times V \quad (3.7)$$

Where:

A = area of suction end (m^2)

V = volume (m3) of the air and it is a function of the pipe length and diameter.

The power of the blower

The blower (shown in Plate 3.3) power P is expressed as

Plate 3.3 Centrifugal Blower

$$P = \frac{QP}{229u} \qquad (3.8)$$

Where:

Q = flow rate (cfm)

p = Pressure (psi)

u = efficiency

3.3.3 Forge Configuration

This refers to the size of the forge. It entails the diameter and height of the stove forge facility. The size of the forge is a function of the amount of the fuel to be loaded and consumed per unit time (FCR) to the specific gasification rate (SGR) of biomass such as charcoal.

The amount of fuel in kg of charcoal required to heat up a given amount of metal for a given time is determined experimentally.

The volume of spherical crucible required to accommodate this amount of charcoal was estimated as

$$v = \frac{1}{3}\pi r^2 h \qquad (3.9)$$

The forge height, length and width is determined by the human modulo which entails the human comfort and safety to work on the forge.

The forge height is taken as 1.56m corresponding an average human height

With the furnace height measuring 0.75m = to waste line height of human blacksmith.
The width and length of the forge > than the diameter of forge furnace
Therefore, length and width of forge was estimated to be 0.4m respectively.

Exhaust hood of Forge design.

The exhaust hood sizing and amount of sheet metal in area required to fabricate the hopper is determined thus;

The shape of exhaust hood is similar to a sliced rectangular based inverted pyramid shown in Plate 3.4.

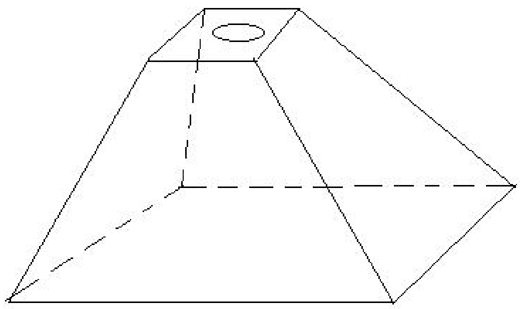


Plate 3.4 Exhaust hood of forge.

Material holding capacity of hopper in volume per batch =

$$v = 1/3x \; h \; x \; [L \; x \; B + (\sqrt{L \; x \; B \; x \; l \; x \; b}) + l \; x \; b] \qquad (3.10)$$

$$= 1/3 \; x \; 0.250 \; x \; [0.430 \; x \; 0.320 + (\sqrt{0.000688}) + 0.200 \; x \; 0.100] = 0.018m3$$

where;

L, l = upper and lower length dimensions of hopper respectively

B, b= upper and lower width dimensions of hopper respectively

h = height dimensions of hopper

If the four sides of the prism are taken as four single trapezoidal sheets joined together

Therefore, Area of any two similar sides of the trapezoidal sheet is

$A1 = 2[½ (L + l) x h]$ and

$A2 = 2[½ (B + b) x h]$

Total Surface Area (TSA) of exhaust hood is expressed as:

T_E = A1 + A2 = 2[½ (L + l) x h] + 2[½ (B + b) x h] (3.11)

This expression can be used to determine the minimum amount in area of sheet metal required for the hopper. For the current work.

3.4 Heat transfer in the furnace

The heat transfer in the furnace is mainly by conduction, convection and radiation.

i. **Conduction heat transfer**

Heat is conducted away through the internal wall of the spherical combustion chamber outwards.

This quantity of heat is mathematically expressed as:

$$Q = \frac{KADT}{DX} \quad (3.12)$$

Q = heat conducted in (KJ/h)

k= Thermal conductivity of the galvanized steel material = 45 (W/mk)

DT = Temperature difference between the internal and outer surfaces of the sphere.

DX = Thickness of the cylinder (m) = 0.001mm

A = Area of the section at right angle. It is expressed as for the hemisphere as:

$$= 2\pi r^2 \quad (3.13)$$

For a metal surface material of multiple surfaces $\sum_n^Q = kA_n\, DTn/Dx$

n= 1, 2, 3, 4, 5 and 6

dx = thickness of the solid (m)

ii. **Convection heat transfer**

Convection is usually the dominant form of heat transfer in liquids and gases. The dominant fluid here is the air circulated within the furnace. It is mathematically, expressed as;

$$Q = h_cA\,[T_2 - T_1] \quad 3.14$$

Where;

h_c = Coefficient of convective heat transfer for air

A = Area of surfaces not perpendicular to direction of heat flow

$T_2 - T_1$ = thermal difference between surface temperature t_2 and air temperature t_1

In the forge furnace, the fluid is air, while the furnace wall and biomass fuel serve as the solid media. The rate at which heat is transferred within the forge is calculated from a coefficient based upon the temperature differences of the surfaces.

h_c = 10 -100 (W/(m^2 K) or W/(m^2 ° C) for free moving air

A is in m^2

Assuming no heat lost,

iii. Radiation heat transfer

The total radioactive flux throughout the internal surface of area A of the forge furnace and absolute temperature T is given by the Stefan- Boltzmann law, which is mathematically expressed as;

$$Q = FA\sigma T^4 \quad (3.15)$$

where;

Q = rate of radiation heat transfer (KJ/h),

T = Absolute temperature of hot and cold bodies respectively

F = Factor depending on surface geometry,

σ = Stefan – Boltzmann constant = 5.6703 x 10^{-8} (W/m^2 k^4)

A = total area of emitting surfaces of the forge furnace

Total heat losses from the operating temperature of the forge furnace is evaluated as;

$$Q_{conduction} + Q_{convection} + Q_{radiation} \quad (3.16)$$

3.5 Bill of Engineering Materials and Evaluation

The Table 3.5 Shows materials and their quantities used in the production of the blacksmith forge furnace.

Table 3.4 Bill of Engineering Materials and Evaluation (BEME) for Blacksmith Forge.

S/No	Items	Description	Quantity	Dimension	Unit	Total cost

					cost	(₦)
1	Mild steel sheet metal		1 roll			150,000
2	Mild steel rod		1	1m		50,000
3	Blower		1			100,000
4	Mild steel pipe		6			80,000
5	Forced draft fan		1 roll			120,000
6	Angle bar		1.5meter			70,000
7	Bolts and nuts		Lot			30,000
8	Hollow square pipe	Mild steel	1/2 inch	1m		60,000
9	Wirings/Electricals		Lump			50,000
10	Paint	Liquid based	1 liter	1 can		20,000
11	Biomass					50,000
12	Miscellaneous					40,000
13	Workmanship					80,000
14	**Total**					900,000

The schematic and pictures of the fabricated blacksmith forge are shown in Plate 3.5, 3.6

Plate 3.5

Plate 3.6

3.6 Testing

The fabricated forge was tested using it to carry out forging of an aluminium material. The test procedure included the followings:

i. A measured weight of the biomass was loaded on the forge furnace after which it was lit with a lighter to ignite it.

ii. The aluminium work piece was loaded on the furnace and heated up by the lit biomass.

iii. The blower was switched on and the air flow regulated until it was set to full throttle to enhance its combustion.

iv. The furnace temperature was recorded using a thermocouple and the aluminium work piece was brought out intermittently for impact hammering to reshape it.

v. After reshaping the facility was switched off and the time taken for the entire process was recorded and the amount of biomass utilized.

vi. The process was repeated for 5 different runs and the values of time per run to reach thermal softening temperature and amount of biomass utilized were recorded.

CHAPTER FOUR
RESULT AND DISCUSSION

4.1 Result

The results of the experimental testing as recorded is shown in the Table 4.1.

Table 4.1: Time-taken and forging temperature attained of aluminum using the fabricated forge facility

Test number	**1**	**2**	**3**	**4**	**Average**
Enhanced forge temperature (^{o}C)	646	736	848	938	792
Time(min) to attain thermal softening temperature.	7	6	5	4	5.5
Amount of biomass used	150	300	450	600	375

From the test analysis, the following computation were made:

Average weight of charcoal before loading = 375g

Average weight of charcoal after given time t

Weight of char residue produced

% char produced = $\frac{x}{1}$ x 100= 25%

4.2 Forging Parameters

After the successful fabrication of the improved forge using the locally sourced materials, various tests and evaluations were carried out to determine several variables and parameters needed for conclusion.

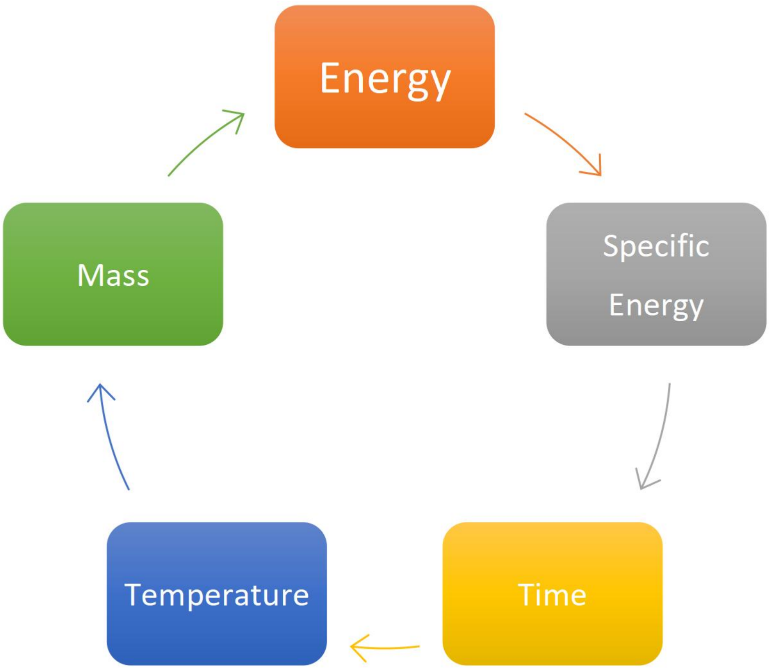
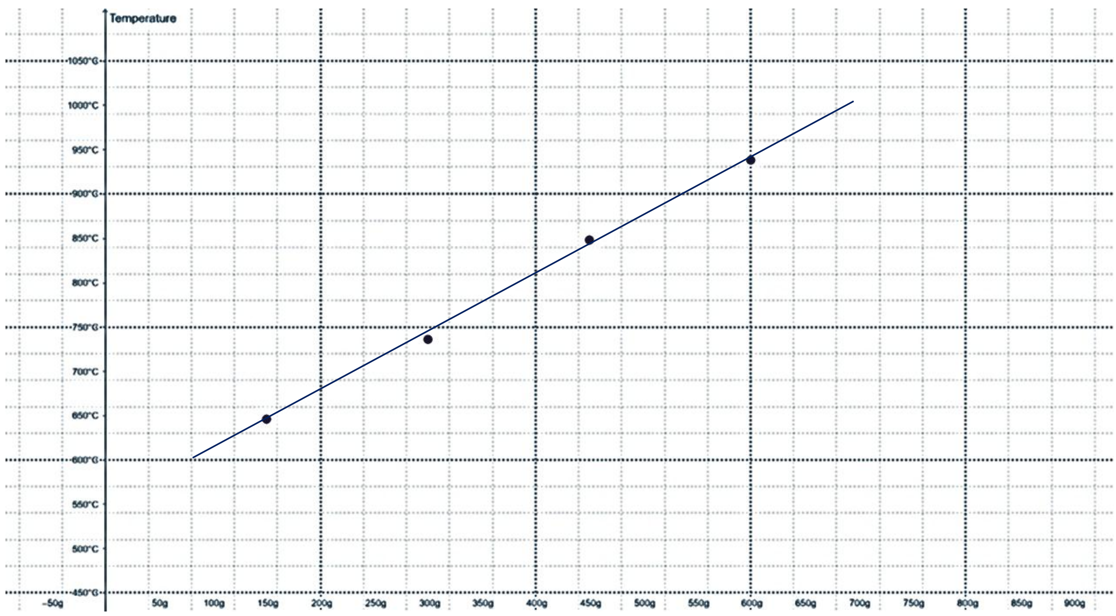
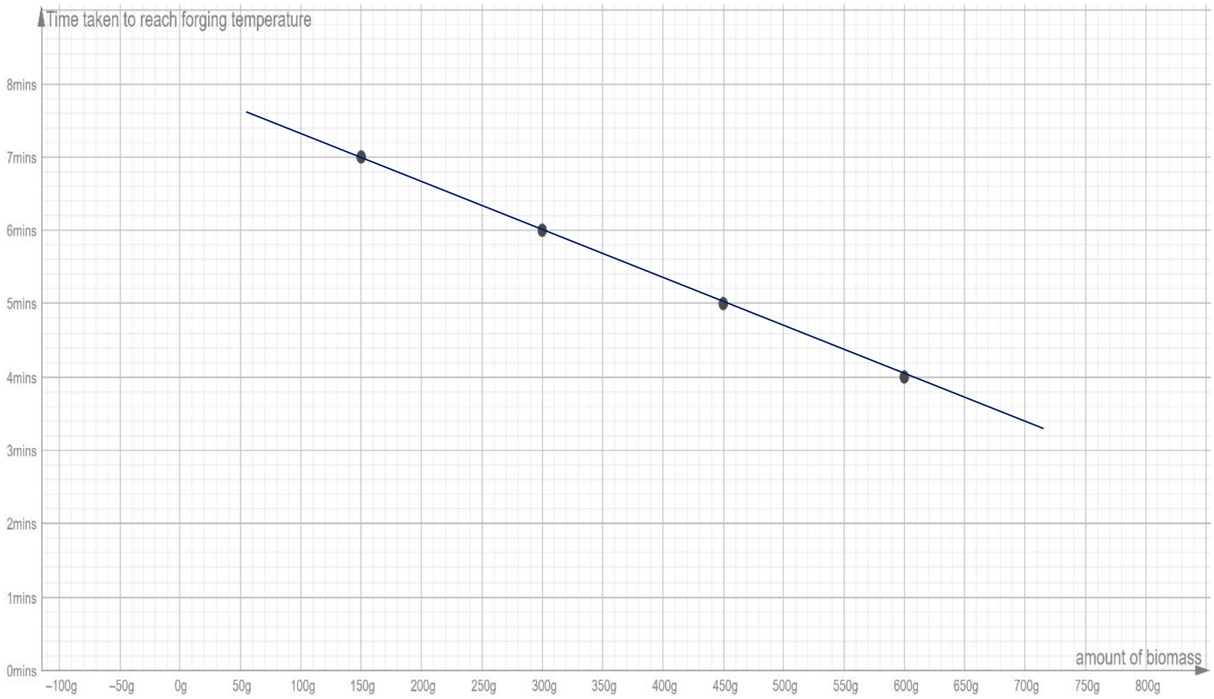


Plate 4.1 Forging parameters



The graph above shows the correlation between the amount of biomass and the temperature attained in the forging facility. The relationship between these variables is directly proportional. An increase in the amount of charcoal used for combustion resulted in a direct increase in the temperature attained in the forge.

When an initial mass of 150g of coal was ignited and the electric blower was used to increase the rate of combustion, the temperature values recorded were in the range 640^{o}C to 650^{o}C with an average of 646^{o}C. Further tests with increased mass of 300g, 450g and 600g reached temperatures of 736^{o}C, 848^{o}C and 938^{o}C respectively.



Graph 2: Plot of time taken to reach forging temperature against amount of biomass (charcoal) used

The graph above shows the time taken in minutes for the temperature in the forge facility to reach the softening temperature of the aluminium specimen. It was observed that the larger the mass of biomass (charcoal) used, the lower the time taken for the temperature to reach forging temperature.

A mass of 150g of charcoal combusted resulted in the softening temperature reached in almost 7 minutes. Further tests showed a decline in amount of time taken (6 minutes, 5 minutes, 4 minutes, with an average of 5.5 minutes across all the tests).

Plate 4.2 Firing test of the fabricated forge facility

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The experimental results obtained from the thermal performance tests carried out on the fabricated forge showed that the inclusion of a forced draft provided improved heat generation by enhancing combustion of the biomass fuel. From the Tables of result for the forge testing it is concluded that as the mass of the work piece increases, more heat and hence more biomass is required to carry out the forging process at the softening temperature of the work piece. The time required to reach the thermal softening temperature of the work piece is a function of the forced draft and the amount of biomass. In the present era where renewable energy has become a viable source of alternative energy, the use of readily available biomass fuels such charcoal has become highly necessitated especially when refined to reduce its environmental unfriendly contents which are emitted during combustion. Charcoal is also cheap to make using locally sourced materials such as wood. The research objectives outlined in the present work was completed to help achieve the goal of developing an affordable forge facility that can be locally produced and used in Nigeria for industrial and research purposes.

5.2. **Recommendation**

Following the successful design, fabrication and testing of the solar powered forge facility, the following recommendations were made.

i. Further research work should be carried out on the project for optimization especially with the use of different types of biomasses with varying emissions and heating value to ascertain some of the most suitable and environmentally friendly biomass.

ii. Government intervention should be sought to promote our local capacity building and to bring about mass production of the locally made facilities such as the blacksmith forge for research and academic purposes.

iii. Dedicated research could be explored to test the viability of using alternative energy sources to power the forge air flow system.

REFERENCES

1. **Adebayo**, R.A and Oke, P.K (2018). Current Journal of Applied Science and Technology 25(4): 1-11, 2017; Article no. CJAST.38696. ISSN: 2231-0843, NLM ID: 101664541.
2. **Adedoyin,** S.F, A. L. Kehinde, and A. F. Sodunke, (2011). Potentials of and socioeconomic benefits of selected ecotourim centres in Ijebu Zone of Ogun State, Nigeria. Centre Point Journal 17(1), 2011, Pp: 53-60.
3. **Ajiboye** TK, Adeyemi MB. Computer aided design of rectangular and circular shaped electrical furnaces. Nigeria Journal of Mechanical Engineering. 2003;3:64 -73.
4. **Anamgba**, A.O. and Azubuike, C.R. (2012). The substance of Economics, Aba, Alpha Publishers, P.59-61.
5. **Anyaele,** J.U. (2003) Comprehensive Commerce for SSS WASSCE, NECO, GCE and JAMB, Surulere-Lagos, A. Johnson Publishers. P.42

6. **Anyakoha**, E.U. (May, 2012) Strategies for positioning Vocational Education for Sustainable Development in Nigeria, Journal of Occupation and Training (JOT), Vol.5 No.3, School of Agriculture and Vocational Studies, AIFCE, Owerri, P.I.
7. **Atteh,** D.O. (1992). Indigenous local knowledge as a key to local development possibilities, constraints and planning issues, studies in technology and social changes, No 20. AMES: IOWA State University, Technology and Social Change Program. 1992.
8. **Bealer,** W. (1996). The art of Blacksmithing. Castle books Revised editioned.
9. **Bunty,** LLC, (2019). Copper Forging Guide. Accessible on https://buntyllc.com/copper-forging/
10. **Catherine** Adu, E. D. (2014). The Assessment of the Blacksmithing Industry in Ghana. Arts and Design Studies ISSN 2224-6061 (Paper) ISSN 2225-059X (Online) Vol.24, 46-56.

11. **CFS** Machinery Co.,LTD (2024). Brass Forging. https://www.dropforging.net/brass-forging.html Copyright © 2024 Drop Forging.

12. **Davis,** S.M. (2016). Design, construction, and evaluation of a gas forge. BioResource and Agricultural Engineering BioResource and Agricultural Engineering Department California Polytechnic State University. San Luis Obispo

13. **Degarmo**, E. Paul; Black, J. T.; Kohser, Ronald A. (2011). Materials and Processes in Manufacturing (11th ed.). Wiley. ISBN 978-0-470-92467-9.

14. **Doege,** E., Behrens, B.-A (2010). Handbuch Umformtechnik: Grundlagen, Technologien, Maschinen (in German), Springer Verlag. p. 7

15. **Ebmpapst**. (2017). Centrifugal-Fans and Blowers. Retrieved June 5, 2017, 17:20,from:http://www.ebmpapst.com/en/products/centrifugalfans/centrifugal_fans.html

16. **Eboh,** e. a. (1995). Sustanable Development: The theory and implication for rural Nigeria in rural Development in Nigeria: Concepts processes prospect. Auto century publishing compony Limited.

17. **Edward** L.S. (1995). Build a Homestead Forge and Fabricate Your Own Hardware. Backwoods Home Magazine. Retrieved February 19, 2017, 19:32, from:http://www.fastonline.org/CD3WD_40/JF/JF_OTHER/SMALL/Build%20a%20homestead%20forge%20and%20fabricate%20your%20own%20hardware...By%20.pdf

18. **Elenwo,** M (2021). Hhowing blacksmithing as an alternative income earner to unemployed nigerians and other parts of the world for sustainable development: elele alimini blacksmithing in focus. Sapientia Foundation Journal of Education, Sciences and Gender Studies (SFJESGS), Vol.3 No.3 September, 2021; pg. 271 – 296 ISSN: 2734-2522 (Print); ISSN: 2734-2514 (Online)

19. **Ezeadichie**, U.E (2002). External influence on nation building in Nigeria. A Critic. (Conference Paper, Montair State University, New Jersey, U. S. A.

20. **Farinia** Group (2018). Hot Forging: Main Considerations, Materials and Applications. Accessible on: https://www.farinia.com/en/blog/hot-forging-manufacturing-process-and-its-undoubted-advantages.

21. **Hawryluk,** M et al., (2023). Development of Preliminary Precision Forging Technology and Concept for Tools Used to Reforge 60E1A6 Profile Needle Rails with the Use of Numerical and Physical Modeling. Journal of Materials 2023, 16(5), 2103; https://doi.org/10.3390/ma16052103
22. **Houzz.**I.E**.** (2016). Ghana Wrought Iron Workers. Retrieved April 11, 2017, 09:42, from:https://www.houzz.ie/professionals/wroughtironworkers/c/Ghana.
23. **Joyce,** T. (2002) The Blacksmiths Art from Africa Life Force at the Anvil, Nigeria: Wikipedia, the free Encyclopedia, P.1-3
24. **Kanu,** I.N. Njoku, J.U, and Nwachukwu, E.O. (May 2012) Entrepreneurship Education and Youth Empowerment: Challenges and Prospects, Journal of Occupation and Training (Jot), Vol.5 No 3, School of Agricultural and Vocational Studies, AIFCE, Owerri, P.74
25. **Kocanda**, A (2013). Developments in the analysis of side forces in forging dies. Conference: 6th International Seminar on Precision ForgingAt: Kyoto.
26. **Kumar**, S, Kharat , A.B and Khotka, S.D (2022). An Overview of Forging Process and Defects in Hot and Cold Forging. International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056. Volume: 09 Issue: 07 | July 2022.
27. **Mahendra** G, Nilesh AJ. (2014). An overview of forging processes with their defects.International Journal of Scientific and Research Publications. 2014;4:1-2.
28. **Mai** B, Zakaria U and Alhaji G (2022). Assessment of Local Blacksmithing Industry in Maiduguri, Borno State Nigeria. International Journal of Information, Engineering & Technology Volume 11, Issue 7, PP 47-54, ISSN: 2360-9194, April, 2022. Double Blind Peer Reviewed International Research Journal. Journal Series: Global Academic Research Consortium (garc).
29. **NICKEL** Institute (2019). STAINLESS STEEL FORGINGS. A DESIGNERS' HANDBOOK SERIES NO 9016. Produced by AMERICAN IRON AND STEEL INSTITUTE
30. **Nwombu,** U.K. (October, 2019) Arts Entrepreneurship and Sustainable Development in Nigeria: Visual Arts in Focus, South-South Journal of Humanities and International Studies, Vol.2 No.4, A Multi-Disciplinary

Journal of the Faculty of Humanities, IAUE, Port Harcourt, Rivers State, Nigeria, P.483

31. **Obikwelu,** K. (1999). Development of Auto component part industry in Nnigeria. Auto component part industry in Nigeria magazine by National Automotive council.

32. **Oke** P.K. (2007). An evaluation of improved local blacksmith process. Journal of Engineering and Applied Sciences. 2007;2(8):1255- 1261.
33. **Oke**, P. K., & Aderoba, A. A. (2000). Mechanization of Heat Treatment Facilities in Local Blacksmith. Journal of Engineering Management, 1, 20-26.
34. **Okopo**, and U. E. Ezeadichie, (2003). Indigenous knowledge and sustainable development in Africa: The Nigeria Case. (The 5th World Archaeological Congress, Washington D. C.
35. **Oladimeji** Y.O (2013). Potentials Of and the Socio-Economic Benefits of Blacksmithing Production in Promoting Agricultural Development and Poverty Alleviation in Kwara State, Nigeria. International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol. 3, Issue. 6, Nov - Dec. 2013 pp-3809-3817.
36. **Oladimeji,** Y.U (1999). An economic analysis of artisanal fisheries in kwara state, Nigeria. Unpublished MSc Thesis. Federal University of Technology, Akure, Nigeria.

37. **Online** Etymology Dictionary (2017). Etymonline.com. Retrieved March 9, 2017. 9:02, from: http://www.etymonline.com/index.php?term=smith"
38. **Oni,** T.O and K. O. Lawal, (2003). Development of small scale manufacturing industries. Cornerstone of Sustainable Economic Self Reliance. Proceeding of Nigeria Institution of Mechanical Engineers, Akure, 50-57.

39. **Ostermann**, F. (2014). Anwendungstechnologie Aluminium (in German), 3rd Edition, Springer Verlag, 2014, ISBN 978-3-662-43806-0
40. **Otor** P. (2014). The SEGE Blacksmithing Industry in Focus. Retrieved April 11, 2017, 08:05, from:http://theheraldghana.com/sege-blacksmithing-industry-focus.
41. **Oyenenye,** O. Y. (1984). Indigenous Technologies. A Journal West African Studies, 63-64.

42. **Parkinson**, P. (2003). The Artist Blacksmith: Design and Techniques (Hardback). The Crowood Press Ltd: Britain. pp. 43 -68.
43. **Rathi** M.G, Jakhade, N.A (2014), "An Overview of Forging Processes with their defects", International Journal of scientific and Research Publications, Vol.4. No6.
44. **Raw** Materials Research and Development Council (RMRDC) (2007). Cottase level investment. opportunities in state of Nigeria. A Publication of Raw Materials Research and Development Council. 2007; 111-13.
45. **Robert** T. KG. (2007). The Genius of China 300 Years of Science, Discovery and Invention. London.Vol.3. pp. 16-57.
46. **Sackey,** J. K. N., Amoakohene, S. K. (1996). Metal Work Technology. Macmillan Education Ltd. London. pp. 77-134.
47. **Sekhon,** M.S, Barr, G.S and Sukhrajsingh.(2014),"A six sigma approach to detect forging defects in a small scale industry: A case study", International Journal of Engineering and Technical Research Publications, Vol.2No8, pp.33– 40.
48. **Stonis,** M.: Mehrdirektionales Schmieden von flachen Aluminiumlangteilen (in German), In: Behrens, B.-A.; Nyhuis, P.; Overmeyer, L. (ed.): Berichte aus dem IPH, Volume 01/2011, PZH Produktionstechnisches Zentrum GmbH, Garbsen 2011
49. **Thomas-Ogubuji,** L.U, (1989). Blacksmithing: A Metallurgical Assessment. Ife J. of Tech., 1, 1989, 41-50.
50. **Yamba,** P., Akayeti, A. and Larson, E. A. (2017). Re-Design and Manufacture of a Mobile Multi-Blowing Blacksmith Forge. ADRRI Journal of Engineering and Technology, Ghana: Vol. 3, No. 10(2), Pp. 1-12, ISSN-L: 2026-674X, 30th September, 2017.