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Development of a Forging Machine for Improved Blacksmithing in Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author RAA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author PKO managed the analyses and literature searches of the study. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: To perform an investigation in the production processes and methods of operation of the blacksmith forging machine in six blacksmith shops in Nigeria.
Study Design: Qualitative study combined with a survey.
Place and Duration of Study: Study was carried out in five states (Edo, Ondo, Osun, Ekiti and Oyo) in Nigeria between February 2016 to August 2017.
Methodology: Investigation of the production processes was done using questionnaires. The questionnaires were administered to ninety people and they were grouped according to their ages in all the 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.

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Results: The analysis of the questionnaire shows 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 is 85Joules (energy at strike).

Conclusion: The machine has been constructed, tested and compared with the local and imported products using mechanical and microstructural test. The products from the imported equipment have the higher ultimate and fracture stress but lesser ductility than the products from developed equipment because of the occurrence of strain hardening.

Keywords: Forging machine; metallographic; blacksmith; products; strain hardening.

1. INTRODUCTION

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, furnace etc. An ancient indigenous technology is blacksmithing, which is the progenitor of various metal forming operations in the use today and can be found in virtually all major culture of the world. 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 [1]. However, some of Nigeria blacksmiths are traditional producer during the pre-colonial era and even now. They produced simple tools and devices primarily used for agricultural production such as holes, rakes, cutlasses, diggers, spades, head pan and machetes. There are some domestic and industrial products produced through blacksmithing processes which include pails, cooking utensils, kitchen wares, basins, keys, chisel punch, bolts and nuts, hammerheads etc. The forge product of blacksmithing is also very important and highly demanded by those in the construction industries [2].

Heating of workpieces and heat treatment processes are the major operations in the blacksmith shops. The production facilities consist of forging facilities, open furnace with bellow and heat treatment baths. The furnace makes use of palm kernel shell/charcoal to heat the metal and the heated metal is manually forged into desired shape or tool. A primitive heat treatment process is achieved by quenching the forged metal in a container containing water, palm oil or vegetable oil solution [3]. Blacksmith skills were extremely important to early Arkansan to make and repair tools, automobile spare parts, household implements and weapons [4]. The earliest method of producing iron consisted of a small furnace built of clay called a bloomer. Charcoal made to burn hotter by using manually operated bellows; small pieces of iron ore were placed in with the charcoal, and after several hours a small piece of “first sized” iron was produced called a bloom [5]. The bloom could then be hammered into the desired shape to produce tools and weapons. Blacksmiths suddenly became very important and as the production of iron increased, more uses were found and were being learned and developed. Ironmaking spread across Europe and eventually reached Britain by about 450BC [6]. When the Romans colonized Britain, iron production was already thriving established; they built on the already thriving industry to produce weapons and Agricultural tools and implements.

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 labour 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 [7]. 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 [8]. By 1975 wrought iron was no longer being produced and is now classed as an extinct material. Small century onwards by the use of water power, bigger bellows could be operated by a water wheel and large trip or tilt hammers could be built to hammer out the large blooms. The whole process was now on its way to being mechanized. Blacksmiths were also becoming specialized and more in demand to produce weapons, armour and tools. The advent of the imported farm implements and machinery spares parts distorted the activities of local producers, but the increasing scarcity of foreign exchange is now necessitating a change direction to abandon indigenous products [9]. Blacksmith skills are one of the basic skill required to produce innovative appropriate technological implements, unfortunately, local blacksmith shop is about to be phased out due to the influence of western education and rural-urban drift [10]. The problem of inflow of improved western industrial products gives blacksmiths little room to improve on their products in accordance with modern appropriate technology innovation. Nigerian prefers foreign products to the products of the local blacksmith. The situation has made the blacksmiths to become a part-time engagement base on the demand for the products from individual customer.

The development of indigenous technology for developing small-scale industry, in which blacksmith shop included, is important for the development of industries in Nigeria) [11]. Based on the identified problems, this study will examine how to adapt operating procedures to conform to the modern forging practice by introducing forging machine (electric hammer) and the manufacturing process is redesigned to improve the quality and quantity of the blacksmith products.

2. MATERIALS AND METHODS

2.1 Site Studies

The instrument used for this research were questionnaires to investigate the production processes and the methods of operation of the blacksmith equipment in six blacksmith shops in five states (Edo, Ekiti, Ondo, Oyo and Osun) in Nigeria to identify the problems encountered during the processes. Three people were selected randomly and interviewed using questionnaires. The questionnaires were administered to ninety people and they were grouped according to their ages in all the states. It was on these groups that the findings were based. The statistical tools used for the description of the response after the questionnaire was the pie chart. The results were used as a basis for the design of forging machine. Calculated forging forces and strokes/min with variable masses are shown in Table 1.

- **Determination of velocity of the piston in (m/s)**

$$V = 2\pi NR \tag{1}$$

N = speed of the machine in (rpm) revolution per minute
V = Velocity of the piston in (m/s)
R = radius of the piston in (m)

- **Determination of the acceleration of the piston in m/s^2**

$$V = u + at \tag{2}$$

V = velocity of the piston in (m/s)
U = initial velocity in m/s)
t = time taken in (second)

- **Determination of impact force of the hammer in (N)**

$$F = ma \tag{3}$$

F = impact force in (N)
M = mass of the hammer used in kg
a = acceleration of the hammer in m/s

- **Determination of hammer stroke per minutes in (M)**

$$Pt = F \times H \tag{4}$$

P = power transmitted to the machine in (Kw)
t = time taken in minutes
F = impact force in (N)
H = hammer stroke per minutes in (M)

- **Determination of Angular velocity of the flywheel in rad/sec**

$$\omega = \frac{2\pi N}{60} \tag{5}$$

ω = angular velocity in rad/sec
N = speed of the shaft = 30rpm

- **Determination of the mass of flywheel in (Kg)**

$$M = 2\pi RA\rho \tag{6}$$

Where:

M = mass of the flywheel in (Kg)
R = Radius of the flywheel in (m)
ρ = density of the flywheel material (Mildsteel 7850kg/m^3) [12]
A = Area of the flywheel in (m^2)

Where:

A = bt
b = width of the flywheel in (m)
t = thickness of the flywheel in (m)

- **Determination of Moment of Inertial of the flywheel in (Kgm^2)**

$$I = ½ MK^2 \tag{7}$$

Where:

I = moment of the inertia in (Kgm^2)
M = mass of the flywheel in (Kg)
K = $\frac{D}{2}$ = radius of gyration of the flywheel in (m)
D = diameter of the flywheel in (m)

- **Determination of Energy stored in the flywheel in (Joule)**

$$E = \frac{1}{2} I\omega^2 \tag{8}$$

Where:

E = energy stored in (Joule)
I = moment of inertial in (Kgm^2)
ω = angular velocity in (rad/sec)

- **Determination of work done by flywheel per cycle in Joule**

$$W = \frac{P\ X\ 60}{N} \tag{9}$$

W = work done by flywheel per cycle in (Joule)
P = power of reduction gear motor 2.5kw
N = speed of the shaft in revolution per minute

Table 1. Calculated forging forces and strokes/min with variable masses

Masses (kg)	Forging forces (N)	Strokes/min m
1	141.6	0.59
2	283.2	0.295
3	424.8	0.197
4	566.4	0.148
5	708.0	0.118
6	849.6	0.098
7	993.2	0.084
8	1132.8	0.074
9	1274.4	0.066
10	1416.0	0.059

Table 2. Summary of the choice of materials selected for the fabrication of components parts of forging machine

s/n	Machine components	Criteria for material selection	Material selection	Justification for material selection
1	Frame	It must be massive, solid, rigid and firm. It must be able to carry the weight of all other components.	U-channel mild steel	Mild steel is readily available cost of purchase is minimal.
2	Hammer (piston)	It must be strong and have the ability to withstand impact shocks.	Mild steel	Mild steel is readily available cost of purchase is minimal.
3	Bolt and Nuts	It must be strong and have the ability to connect and fasten the frame and other components together.	Mild steel	Mild steel is readily available high resistance to bending.
4	Working bed	Ability to withstand the force of impact of the piston (hammer).	Mild steel	Mild steel is readily available high resistance to bending.
5	Flywheel	It must be able to serve as a reservoir. Ability to store energy when the supply energy is more than the requirement and releases energy. When the requirement of energy is more than supply.	Mild steel	Mild steel is readily available.
6	Reduction gear	Ability to convert electrical energy into mechanical energy.	Mild steel, and coil of wire	It is readily available. The coil wires are driven by magnetic force extended by a magnetic field.
7	Shaft	Ability to transmit power.	Mild steel	Mild steel is readily available.

2.2 Materials Selected for Machine Components

Some design factors were taken into consideration in the choice of materials for the design of the forging machine so as to enhance its efficiency, reliability, workability, stability and sustainability. Table 2 gives a summary of the choice of materials selected for the fabrication of components parts of forging machine.

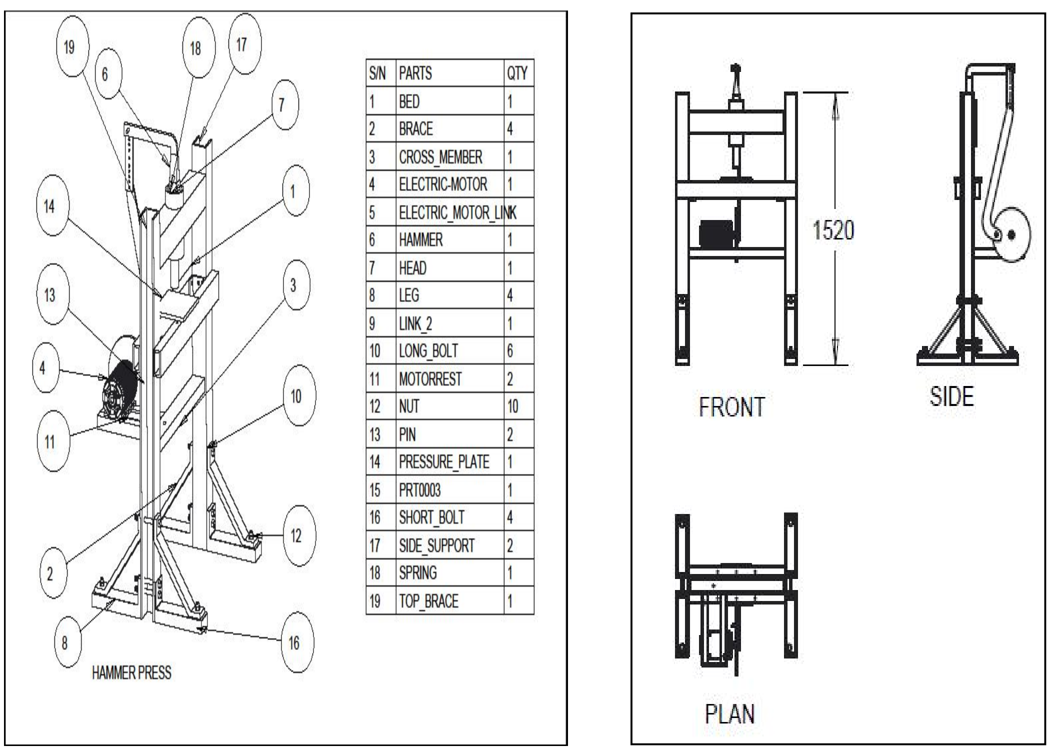
2.3 Features of Developed Forging Hammer for Blacksmith Shop

The problems observed through questionnaire from the local blacksmith shops which led to the development of a forging machine (electric hammer) to save time in striking the heated metals and to improve the quality and quantity of the products in order to meet the demand of the customers. All the dimensions used in the design are based on the analysis of the interview of the dimension of the products produced in the local blacksmith shops. The average maximum forging forces of the machine are 1416N.

The forging machine, electric hammer in Figs. 1 & 2a, b, c. is made up of the following parts, angle bar, U-channel mild steel, flywheel reduction gear motor, masses, piston, working table and adjustable bar. The principle behind the operation of the machine is very simple, when the machine is switched on, the shaft in the motor is the rotating machine element which transmits power and delivered to the shaft by some tangential forces and resultant torques (or twisting moments) set up within the shaft, and permits the power to be transferred to the flywheel. The flywheel will store energy during the period when the supply of energy is more than the requirement and releases it when the requirement of energy is more than the supply. The rotation of the flywheel will cause the piston to move upward and strike the workpiece which rests on the working table.

2.4 Performance Evaluation of the Developed Forging Machine

In evaluating the performance of the 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 as shown in Plates 1 and 2.



S/N	PARTS	QTY
1	BED	1
2	BRACE	4
3	CROSS_MEMBER	1
4	ELECTRIC-MOTOR	1
5	ELECTRIC_MOTOR_LINK	
6	HAMMER	1
7	HEAD	1
8	LEG	4
9	LINK_2	1
10	LONG_BOLT	6
11	MOTORREST	2
12	NUT	10
13	PIN	2
14	PRESSURE_PLATE	1
15	PRT0003	1
16	SHORT_BOLT	4
17	SIDE_SUPPORT	2
18	SPRING	1
19	TOP_BRACE	1

Fig. 1. Isometric view of electric hammer

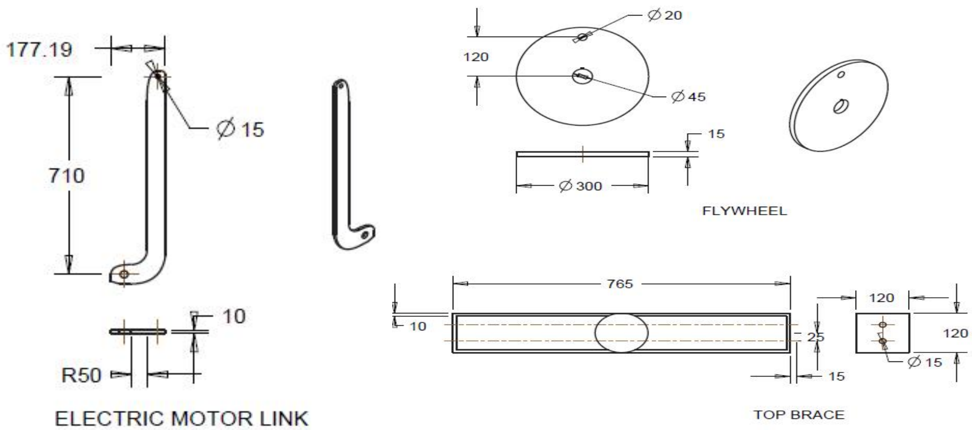


Fig. 2a & b. The electric motor link and brace of electric hammer

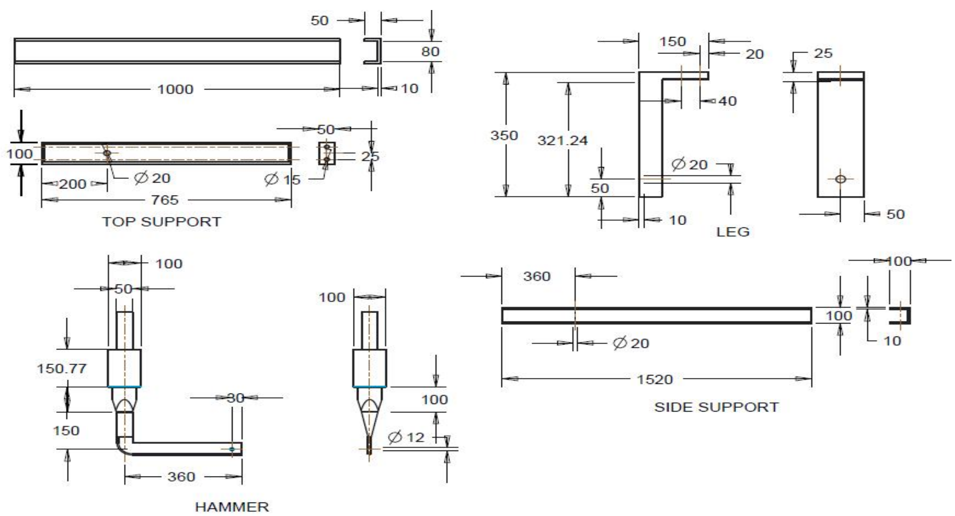


Fig. 2c. The support parts of electric hammer

Plate 1. Fabricated forging machine (electric hammer)

Plate 2. Sample of the products produced by developed forging machine (on the field)

Table 3. Cost analysis of materials and machining parts of forging machine (electric hammer)

s/n	Materials	Description/specification	Quantities	Rate (N)	Total (N)
1	U-channel	Mild steel (1520 x 120 x 90)mm	4	7,800	31,200
2	Flat bar	Mild steel (1200 x 100 x 10)mm	2	3,000	6,000
3	Angle iron	Mild steel 2” (2ft)	2	2500	5,000
4	Spring	Helical	1	1,000	1,000
5	Flywheel	Mild steel (300 x 50)mm	1	3,500	3,500
6	Working table plate	Mild steel (250 x 220 x 30)mm	1	1,200	1,200
7	Reduction gear motor	Power 3.5kw	1	25,000	25,000
8	Piston (hammer)	Mild steel 50mm diameter	1	10,000	10,000
9	Hammer cylinder (plate)	Mild steel	1	8,000	8,000
10	Cutting disc		3	600	1,800
11	Grind disc		2	1,000	2,000
12	Drill B.H	(6-16)mm	10	350	3,500
13	Electrodes	Gauge 10, gauge 12	2pcs	5,000	10,000
14	Bolts and Nuts	M14	30	120	3,600
15	Switch on and off (reduction switch)		1	4,000	4,000
16	Paint	Emulsion	5 litres	2,500	2,500
17	Transportation				15,000
18	Workmanship				30,000
19	Miscellaneous expenses				30,000
Total					N193,300

2.4.1 Specimen preparation

The forging machine (electric hammer) in Plate 1 has been fabricated from the locally available materials. Mechanical test and metallographic examination were carried out on one of the selected product (chisel) from the local blacksmith equipment, developed equipment and imported one as a control. Each blacksmith product was brought from the five states. The tests were carried out in Metallurgy and Material Engineering Department of Engineering materials and development institute (EMDI), Akure, Ondo State, Nigeria. Samples of selected blacksmith products were machined into shapes and sizes suitable for the tests.

Hardness Test (Rockwell and Vicker): For hardness test, using Rockwell and Vicker hardness tester, the selected product (chisels) were grounded using emery paper of grades 220, 320, 400 and rough polished on glycerol-lubricated silicon carbide paper. This was done slowly to produce a very smooth surface and to avoid heating and oxidation. All the damages arising from the specimen preparation were totally eliminated during grinding and polishing processes. A load of 100 kg was pressed on each test specimen for 10 seconds with the aid of an indenter. The formula used for the Vicker test was

$$HV = \frac{2P \sin 68^0}{L^2} \quad (10)$$

where:

HV = Vicker Harder
P = Load in kilogram
L = length of diagonal of the impression in (mm)

Tensile Test: The tensile test was carried out using the specimens of blacksmith products from the local, developed and imported equipment. These products (chisels) were turned on lathe machine to standard tensile pieces. These "dog bone" shape specimens have a specification of 5mm diameter at the middle with 177 mm of length. The tensile test pieces were tested to fracture on extensometer. The dimension of the gauge zone was determined as well. The average value of five tensile test trial data from each product of local, developed and imported blacksmith was taken and recorded.

3. RESULTS AND DISCUSSION

3.1 Analysis of Questionnaires

The visitation to six blacksmith shops of each five states (Edo, Ekiti, Ondo Osun and Oyo) in Nigeria covered three months and the personal interview revealed that most of the blacksmiths were encouraged by their family because blacksmithing is a family business while about 25% actually created interest to engage in the business. It was known through their interview that they do not have a problem in the sales of their products but they are unable to meet up with the demand of the customers, in term of quantity and quality. It was observed that the blacksmiths and the apprentice were engaged in fashioning varieties of domestic household utensils, industrial and agricultural products. It was discovered that no newly established blacksmith shops for the past sixteen (16) years.

The Table 4 show the analysis of the ages of the people involved in the business which were noted and recorded during the interview.

Looking through the analysis of all the ages of the people engaged in the local blacksmith shop in the selected states during the study, it was discovered from the pie-chart that 20-29 years are 6%, 30-39 years are 12%, 40-49 years are 28%, 50-59 years are 40% and 60-69 years are 14%.

The result in Table 4 shows that the age of 50-59 years was the highest degree and the calculation of the mode with its histogram at this degree reveals 53 years. This is an indication that the people that engaged in the business need some equipment that will reduce their stresses and forces in striking the heated metals in order to improve the quality and quantity of their products.

3.1.1 Metallographic examination

The surface of a sample of each of the specimen was ground perfectly flat and mirror-like surface using grade 220, 320, 400, 500 and 600 emery paper ranging from coarse to fine. Polishing was done using alumina (Al_2O_3) paste (6µm down to 1 µm) extended with distilled water into a slurry. Submicron diamond was finally used to produce a mirror surface finish at end of the polishing operation. The entire surface of the specimen was dipped into the enchant (Nital, 2% HNO_3 and 98% methyl alcohol) for about 10 seconds after which the surface was washed with water and dried. The specimens were taken to the electronic microscope for metallographic examination and the picture showing the arrangement of the grain structure.

3.2 Analysis of the Results

3.2.1 Hardness test results

The results from Table 5 reveals that the hardness of the sample from imported equipment was the highest while the low value of hardness was the sample from the local blacksmith equipment. The low value of hardness observed in local blacksmith product was due to inappropriate heat treatment process and poor forging.

3.2.2 Tensile test results

The results from Table 6 show that the local blacksmith product has the highest average percentage elongation than the products from developed and imported equipment. This is an indication that, the re-crystallization removes the strain hardening effect and hence reduces strength but increase the ductility. The product from the imported equipment has the highest ultimate and fracture stress but that of the developed equipment is higher than the product from the locally made one because there was an occurrence of strain hardening and the dislocation density increases due to cold deformation. Therefore, the ability of the product to withstand wear and tear is more than the local blacksmith product.

Table 4. Analysis of age of people engaged in blacksmith job

s/n	States	20-29	30-39	40-49	50-59	60-69	Total
1	Edo	1	3	5	5	4	18
2	Ekiti	2	2	5	6	2	18
3	Ondo	2	2	3	10	2	18
4	Osun	1	1	6	6	4	18
5	Oyo	0	2	6	9	1	18
Total		5	11	25	36	13	90

Table 5. Hardness test results (Rockwell and Vicker hardness number)

Specimen	Trial	Label product	Reading 1		Reading 2		Reading 3		Average	
			HV	HRC	HV	HRC	HV	HRC	HV	HRC
Chisel	1	Imported	341.2	20.6	210.8	13.5	252.5	22.7	234.8	18.9
	2	Improved	189.4	8.3	188.6	8.1	197.1	10.2	191.7	8.8
	3	Local	178.5	7.4	175.4	7.0	180.2	8.2	178.0	7.5

Table 6. Tensile test results

		Trials	Product from imported equipment	Product from improved equipment	Product from local equipment
Chisel	Ultimate stress KN/m^2	1	549.0	522.0	440.0
		2	550.0	520.2	445.2
		3	545.0	518.5	438.9
		4	540.0	519.6	430.3
		5	549.0	521.0	442.4
		Ave	546.6	520.3	439.4
Chisel	Fracture stress KN/m^2	1	420.3	410.5	374.0
		2	415.9	405.3	376.5
		3	418.5	401.5	372.0
		4	412.4	407.3	377.2
		5	422.3	402.0	370.9
		Ave	417.9	405.3	373.9
Chisel	Percentage (%) elongation	1	8.5	9.6	10.7
		2	9.0	10.2	11.3
		3	8.5	9.0	11.3
		4	8.5	10.2	10.7
		5	9.6	10.2	11.4
		Ave	8.82	9.84	11.08

Fig. 3a. Metallographic structure of product from imported equipment

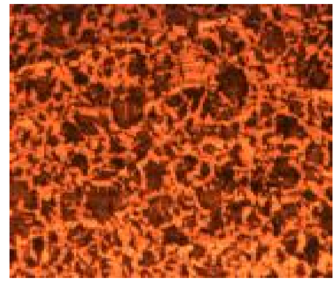


Fig. 3b. Metallographic structure of chisel product from developed equipment

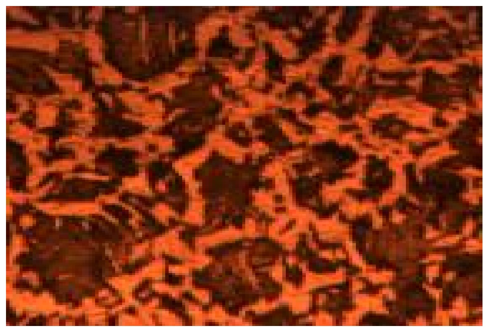


Fig. 3c. Metallographic structure of chisel product from local equipment

3.2.3 Metallographic test results

The micrographs of smith products showing the microstructure and the arrangement of the grain of imported developed equipment and locally made smith products. The white circular features are ferrite while the darker features are pearlite. The arrangement of the grain structures in imported smith product from the micrograph in Fig. 3a shown that they have well-arranged fine grains. Also, the grain structure of the product from developed equipment in Fig. 3b have fine grains arrangement but not as fine as imported product while that of locally made one in Fig. 3c have coarse structure and the grains are not well arranged. The recrystallization of the local product is below the recrystallization temperature due to prolonged forging while the recrystallization of the product from imported and developed equipment is within the recrystallization temperature.

4. CONCLUSION

The study was carried out to develop a forging machine (electric hammer) for improved blacksmith products in Nigeria. The machine has been tested and compared with the local and imported products using mechanical and microstructural test. The performance evaluation of the machine shows that it can compete favourably with an imported forging machine of the same design capacity.

5. RECOMMENDATIONS

In promoting indigenous technology, efforts should be made to encourage the development of more of this important equipment for the blacksmith. Since the machine can compete favourably with the imported one, the blacksmiths should be encouraged to use the machine and should not rely mostly on the imported one. The government should establish a research centre to work with abandon local blacksmith shop so that raw material will be made available with appropriateconsistent elements. Use of scrap from abandoned vehicles should be discouraged since the durability, strength, hardness and ductility properties of the products from the scrap cannot be guaranty because of the uncertainty of the material composition of the products.

The development of this machine will bring about a realist industrial base and sustainable development in Nigeria. For the forging machine to be more effective, high current must be needed to power the reduction gear motor.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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