

## Full Paper

**DESIGN, MODELLING AND FABRICATION OF PEDAL POWERED HACKSAW****R. Abu***Department of Mechanical Engineering, University of Ibadan, Nigeria.  
aburahaman@yahoo.com***K. A. Oladejo***Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.***K. T. Oriolowo***Department of Industrial and Production Engineering, University of Ibadan, Nigeria.***A. J. Adeoye***Department of Mechanical Engineering, University of Ibadan, Nigeria.***ABSTRACT**

Hacksaw is a simple machine used to cut engineering materials like metal pipes and plastic tubing. The hand-held hacksaw is commonly used during fabrication process because it is easy to handle and does not require electricity. However, this hacksaw requires too much effort to use and operator is prone to accident. There is sparse literature on use of pedal powered hacksaw as an alternative. Therefore, this study was planned to design, model, fabricate and evaluate a pedal powered hacksaw using recycled bicycle. Standard design procedures were used to design and fabricate scrap bicycle, base, vice, hacksaw and link mechanism for the pedal powered hacksaw. Autodesk Inventor Professional software was used to model the fabricated machine to carry out its stress analysis. Performance evaluation of the pedal powered hacksaw was carried out on various engineering materials and the results were compared to hand-held hacksaw. It was established that the pedal powered hacksaw saved significant time in cutting and less tedious with fewer cutting strokes. The pedal powered hacksaw, a technological innovation, will save the environment from dumping of scrap bicycles and give the operator on-the-job benefit of a cycling exercise for physical and mental fitnesses.

**Keywords:** Hacksaw, pedal powered, recycled bicycle, sustainable environment and cutting machine.

**1. INTRODUCTION**

Cutting of engineering materials can be done using electric power cutting machine (e.g. band sawing machine, electric portable cutting machine etc.), or manual cutting (e.g. with hand-held hacksaw). The electrically powered machine has disadvantages such as inability to be used in remote areas; it is expensive; and it

requires technical know-how. The disadvantages of hand-cutting method include: it is laborious; it is time consuming; and has low cutting accuracy. All these disadvantages led to the design and fabrication of pedal powered hacksaw machine that uses a less effort pedalling to power and produce uniform cutting of engineering materials such polyvinyl chloride (PVC) pipes, metals and wood, and at the same time serves as an exercising machine. There are several health benefits in pedalling (cycling) including improved cardiorespiratory and muscular fitness as confirmed by Oja et al. (2011).

Several types of pedal powered machine have been fabricated. Some of the machines are pedal powered blender, thresher, water pump and nut-sheller. Girish and Parameswaramurthy (2014) designed conceptual model of water pumping and battery charging cross trainer which is user-friendly, easy to do exercise, save and stores the energy of the users' muscle efforts. When a person operates the lever and the pedal, the centrifugal pump is actuated to pump water from ground sump to the tank. Bahale et al. (2012) designed and fabricated a pedal powered multipurpose machine. It was developed for lifting the water to a height 10 metres and generating 14 V, 4 A of electricity in most effective way. Power required for pedalling is well below the capacity of an average healthy human being.

David (1986) stated that a person could generate four times more power, one-quarter horsepower, by pedalling than by hand-held hacksaw cutting. Pedal powered hacksaw enables a person to drive devices at the same rate as that achieved by hand, but with far less effort and fatigue. Various models of pedal powered hacksaw machine have been designed (Thangaprakash, et al., 2014; Subash, et al., 2014; Kshirsagar, 2015; Vivek, et al., 2015; Khaja and John, 2016; Mogaji, 2016; and Jagadeeswara and Hemachandra, 2017). These models did not use scrap bicycles as materials for fabrication. However, the present study used the bicycle scrap to develop pedal powered hacksaw to save the environment from indiscriminate dumping of bicycle wastes. Therefore, the objective of this study was to design, model, fabricate and evaluate performance of a pedal powered hacksaw for sustainable environment and technological innovations.

**2. MATERIALS AND METHODS****2.1. Design Calculations:**

(a) Calculation of the power production efficiency by chain transmission (Figure 1) was carried out using the method by Khurmi and Gupta (2005).

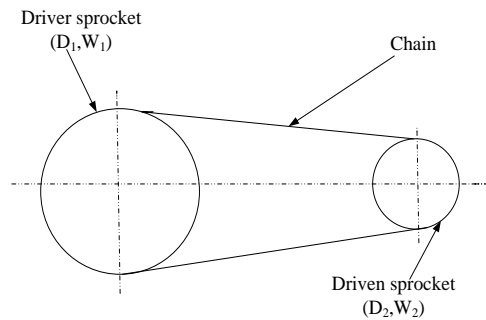


Figure 1: Sprockets connected with chain

Mechanical Advantage,

$$MA = \frac{D_{driver}}{D_{driven}} = \frac{D_2}{D_1} = \frac{\omega_{in}}{\omega_{out}} \quad (1)$$

where

$D_1$  = diameter of driver sprocket, mm

$D_2$  = diameter of driven sprocket, mm

$\omega_{in}$  = input rotational velocity of flywheel, rad/sec

$\omega_{out}$  = output rotational velocity of flywheel, rad/sec

Using  $D_1=560$  mm and  $D_2=286$  mm (as received bicycle scrap), evaluate MA with Equation (1) to obtain Equation (2).

$$MA = \frac{286\text{mm}}{560\text{mm}} = 0.511 \quad (2)$$

The input rotational velocity of flywheel is evaluated as follows:

$$\omega_{in} = \frac{2\pi \times N_{in}}{60} \quad (3)$$

where

$\omega_{in}$  = input rotational velocity of flywheel, rad/sec

$N_{in}$  = cycling speed, in revolution per minute

Using  $N_{in}=120$  rev/min (Suresh *et al.*, 2018), evaluate  $\omega_{in}$  with Equation (3) to obtain Equation (4).

$$\omega_{in} = \frac{2\pi \times 120}{60} = 12.566 \text{ rad/sec} \quad (4)$$

Equation (1) is further simplified to give Equation (5)

$$\omega_{out} = \frac{\omega_{in}}{MA} \quad (5)$$

Using  $\omega_{in}=12.566$  rad/sec and  $MA=0.511$ , evaluate

$\omega_{out}$  with Equation (5).

$$\omega_{out} = \frac{12.566}{0.511} = 24.591 \text{ rad/sec} \quad (6)$$

The velocity of the flywheel is evaluated as follows:

$$V = \omega_{out} \times R \quad (7)$$

where

$V$  = velocity of the flywheel, m/s

$R$  = radius of flywheel

Using  $\omega_{out} = 24.51 \text{ rad/s}$ , and  $r = \frac{150}{2000} \text{ m}$ , evaluate

$V$  with Equation (7).

$$V = 24.591 \times \frac{150}{2 \times 1000} = 1.844 \text{ m/s}$$

The centrifugal force on the flywheel is evaluated as follows:

$$FC = m \times R \times \omega_{out}^2 \quad (8)$$

where

$FC$  = Centrifugal force on the flywheel, Newton (N)

Using  $m=15$  kg,  $r = 0.075 \text{ m}$  and  $\omega_{out} = 24.51 \text{ rad/sec}$ ,

evaluate  $FC$  with Equation (8).

$$FC = 15 \times 0.075 \times 24.591^2 = 680.307 \text{ N}$$

The power output of the flywheel is evaluated as follows:

$$p = FC \times V \quad (9)$$

where

$p$  = Power output, Watt

Using  $FC = 680.307 \text{ N}$  and  $V = 1.844 \text{ m/s}$ , evaluate  $p$  with Equation (9).

$$p = 680.307 \times 1.844 = 1254.486 \text{ W}$$

The torque on the flywheel is evaluated as follows:

$$\tau = FC \times r \quad (10)$$

where

$\tau$  = Torque, Nm

Using  $FC = 680.307 \text{ N}$  and  $r = 0.075 \text{ m}$ , evaluate  $\tau$  with Equation (10).

$$\tau = 680.307 \times 0.075 = 51.023 \text{ Nm}$$

The velocity ratio of the machine is evaluated as follows:

$$VR = \frac{\text{Effort distance}}{\text{Load distance}} = \frac{\text{Length of crank pedal}}{\text{hacksaw cutting stroke}} \quad (11)$$

where

$VR$  = velocity ratio

Using Length of crank pedal = 160 mm and Hacksaw cutting stroke = 200 mm,  $VR$  is evaluated with Equation (11).

$$VR = \frac{160\text{mm}}{200\text{mm}} = 0.8$$

Therefore, the overall efficiency is evaluated using Equation (12):

$$\text{Efficiency} = \frac{MA}{VR} \times 100 \quad (12)$$

where

$MA$  = Mechanical advantage of the machine

$VR$  = Velocity of the machine

Using  $MA = 0.511$  and  $VR = 0.800$ , evaluate efficiency with Equation (12).

$$\text{Efficiency} = \frac{0.511}{0.800} \times 100\% = 63.875\%$$

(b) Chain design calculation of the chain transmission (Figure 1) was carried out using the method by Peter (2014).

The chain length in pitches is evaluated with Equation (13):

$$L = \frac{N_1 + N_2}{2} + \frac{2C}{P} + \left[ \frac{N_2 - N_1}{2\pi} \right]^2 \left( \frac{P}{C} \right) \quad (13)$$

where

$L$  = number of chain pitches, mm

$N_1$  = number of teeth in the driver sprocket

$N_2$  = number of teeth in the driven sprocket

$C$  = center distance, mm

$P$  = chain pitch, mm

Using  $N_1 = 43$ ,  $N_2 = 22$ ,  $C = 541.226\text{ mm}$   
and  $P = 9.525\text{ mm}$ , evaluate  $L$  using Equation (13).

$$L = \frac{43 + 22}{2} + \frac{2(541.226)}{9.525} + \frac{(22 - 43)^2}{2\pi} \left( \frac{9.525}{541.226} \right)$$

$$L = 147.378\text{ mm}$$

The angle of contact between the chain and the sprockets is evaluated with Equation (14):

$$\theta = \pi - 2 \sin^{-1} \left( \frac{P(N_2 - N_1)}{2\pi C} \right) \quad (14)$$

where

$\theta$  = Angle of contact, radians

Using  $P = 9.525\text{ mm}$ ,  $N_1 = 43$ ,  $N_2 = 22$  and  
 $C = 541.226\text{ mm}$ , evaluate  $\theta$  using Equation (14).

$$\theta = \pi - 2 \sin^{-1} \left[ \frac{9.525 (43 - 22)}{2\pi \times 541.226} \right] = 3.024\text{ rad}$$

The chain tension is evaluated with Equation (15).

$$T = \frac{2\pi \times p}{N_1 \times \omega_{in} \times P} \quad (15)$$

where

$T$  = chain tension, N

Using  $p = 1254.486\text{ W}$ ,  $P = 9.525\text{ mm}$ ,  
 $\omega_{in} = 12.566\text{ rad/sec}$  and  $N_1 = 43$ ,  
evaluate  $T$  with Equation (15).

$$T = \frac{2\pi \times 1254.486}{43 \times 12.566 \times 9.525} = 1.532\text{ N}$$

The chain transmission ratio was evaluated with Equation (16):

$$t = \frac{N_2}{N_1} \quad (16)$$

where

$t$  = chain transmission ratio

Using  $N_1 = 43$  and  $N_2 = 22$ , evaluate  $t$  with  
Equation (16):

$$t = \frac{22}{43} = 0.512$$

Connecting rod design calculation is carried out using method by Mogaji (2016). The connecting rod converts rotary motion of the flywheel to reciprocating motion of the hacksaw. The cross-sectional area of the connecting rod was determined in order to safeguard against buckling which is characterized by a sudden sideways deflection of the connecting rod.

The cross-sectional area of the connecting rod is evaluated as follows:

$$A = \frac{w_{bk}}{\sigma_c} \left( \frac{k^2 + aL_h^2}{K^2} \right) \quad (17)$$

where

$A$  = cross-sectional area of the connecting rod,  $\text{mm}^2$

$w_{bk}$  = buckling load acting on the connecting rod

$K$  = radius of gyration between the rotation disc and hinged end of the rod, mm

$a$  = rankine constant of the mild steel

$L_h$  = length of connecting rod, mm

$\sigma_c$  = crushing stress of mild steel material

Using  $K = 100\text{ mm}$ ,  $\sigma_c = 275\text{ N/mm}^2$ ,  $a = \frac{1}{7500}$ ,

and  $L_h = 350\text{ mm}$ , evaluate  $A$  with Equation (17).

$$A = \frac{50}{275} \left( \frac{100^2 + \left( \frac{1}{7500} \times 350^2 \right)}{100^2} \right) = 182.12\text{ mm}^2$$

## 2.2. Modelling of Pedal powered Hacksaw:

A model of the pedal powered hacksaw was developed using Autodesk Inventor Software to produce the different parts in Table 1. The three-dimensional solid model is shown in Figure 2.

Table 1: Material selection

Machine Part	Material Selected
Frame	Aluminum steel
Pedal	Mild steel
Pedal rod	Mild steel
Sprockets (i.e. driver and driven sprocket)	Low carbon steel
Flywheel	Mild steel
Connecting rod	Mild steel
Hacksaw frame	Cast iron
Hacksaw blade	High speed steel
Chain	Plain carbon steel
Base frame	Mild steel
Bearing	Cast iron
Bench vice	Cast steel
Bolts and nuts	Mild steel

The frame, pedal, pedal rod, sprockets and chain were obtained from scrap bicycle.

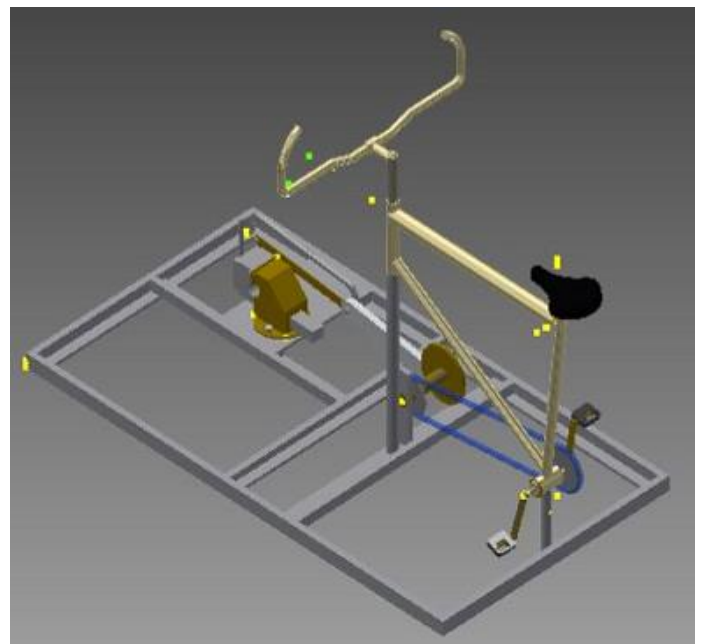


Figure 2: Modelled Pedal Powered Hacksaw



### 2.3. Stress analysis of the developed model:

Stress analysis was carried out on the bicycle frame using a load of 800 N (average weight of an operator of a pedal powered hacksaw) using Autodesk Inventor Software to determine the von mises stress and safety factor as shown in the Figs. 3-4. The von-Mises stress is very small (Fig. 3) which shows that multidirectional stresses on the frame is below allowable stress. The factor of safety of the frame is very high (Fig. 4) which is evidence that the frame will not experience failure when in use. All the results of the stress analyses proved that the model is feasible and can be fabricated.

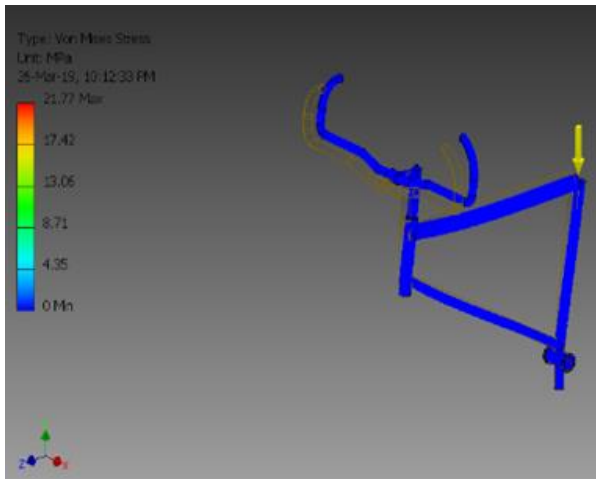


Figure 3: Von mises stress

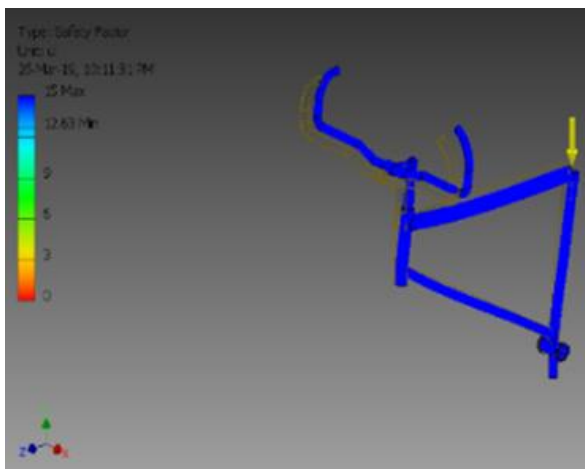


Figure 4: Safety factor

### 2.4. Ergonomic Design of the Pedal Powered Hacksaw:

Ergonomic design of the scrap bicycle was already done by its manufacturer based on ISO 6385 which is ergonomic principles in the design of work systems. The saddle, handlebar and crank centre of the bicycle were ergonomically designed to fit to the frame. This ensured reduction of biomechanical and physiological stresses on the operator of the pedal powered hacksaw.

### 2.5. Fabrication of Machine Parts:

The fabrication of pedal powered hacksaw machine was done as follows:

- Four pieces of angle iron were welded together to form rectangular frame for the base support.
- 34 mm diameter cast iron pipe of 470 mm length and 27 mm diameter cast iron pipe of 168 mm length were welded to the base of the handle and seat of the bicycle frame.

- 800 mm long angle iron (2 x 2 x 2 mm) was welded to the base of the bicycle frame at a distance of 750 mm from the frame end.
- The frame bicycle was welded to the centre of the base frame as shown in Figure 8.
- 750 mm angle iron (2 x 2 x 2 mm) was welded at a distance of 510 mm from the base end.
- 450 mm long angle iron was welded to the centre of the angle iron that is 510 mm away from the end of the base frame; and 35 mm diameter pipe of 250 mm length was welded to the driven sprocket and to the 450 mm long angle iron.
- A bearing seat was constructed and the bearing was tightened to the bearing seat with the aid of bolts and nuts and also allowing the 35 mm diameter metal pipe to pass through it.
- 13 mm drill bit was used to drill the flywheel at a distance of 100 mm from one end of the flywheel using pillar drilling machine.
- The centre of the flywheel was welded to the centre end of the 35 mm diameter pipe.
- 25 mm distance was measured from the two ends of the connecting rod and was drilled using 13 mm and 9 mm drill bits, respectively and the hacksaw end was drilled using 9 mm drill bit.
- The drilled part of the flywheel was tightened to the flywheel and hacksaw using 13 mm and 9 mm bolts and nuts.
- The bench vice seat was constructed and the bench vice was tightened using bolts and nuts.

The fabricated pedal powered hacksaw machine was painted as shown in Figure 5.



Figure 5: Fabricated pedal powered hacksaw

### 2.6. Cost Estimation:

The breakdown for cost of fabrication of the pedal powered hacksaw is shown in details in Table 2. The total cost is thirty-seven thousand and five hundred naira (₦37,500) which is affordable and commensurate with the inherent benefits of the pedal powered hacksaw.

Table 2: Cost estimate for the pedal powered hacksaw

Description of Goods	Quantity	Rate (N)	Amount (N)
Recycled Bicycle Frame	1	4,000	4,000
Bearing	1	2,000	2,000
Bench vice	1	4,500	4,500
23 Ft Angle Iron 2mm x 2mm x 2mm	1	10,000	10,000
35mm Diameter pipe of 4Ft long	1	500	500
Hacksaw and blade	1	1000	1000



Electrode	1 Pack	2,000	2,000
Bolts and nuts	Lots	1,000	1,000
Connecting rod	1	500	500
Flywheel	1	500	500
Painting of machine	5	3,000	3,000
Transportation	-	2,500	2,500
Cost of Labour	-	6,000	6,000
Total			37,500

### 2.7. Performance Evaluation of the Machine:

The performance evaluation of the fabricated pedal powered hacksaw was carried out on various engineering materials (40 mm wooden square, 50 x 50 mm square steel pipe,  $\phi$  25 mm and  $\phi$  32mm circular steel pipes of 1mm thickness) and was compared to hand-held cutting method.

## 3. RESULTS AND DISCUSSION

The detailed results of the performance evaluation of the machine were presented in Figs. 6-7 and Tables 3 and 4, and discussed.

### 3.1. Cutting of 40 x 40 mm Wooden Square Using Hand-Held Cutting and Pedal Powered Hacksaw Method

Cutting of 40 mm x 40 mm solid wooden square was done using hand-held cutting method and pedal powered hacksaw. The hand-held hacksaw took average of 24.67 seconds and 36.00 strokes to cut while pedal powered hacksaw took average of 14 seconds and 23.67 strokes (Figs. 6-7). The powered hacksaw was 10.67 seconds faster with lesser strokes of 12.33.

### 3.2. Cutting of 50 x 50 mm Square Steel Pipe Using Hand-Held Cutting and Pedal Powered Hacksaw Method

Cutting of 50 x 50 mm square steel pipe was done using hand-held cutting method and pedal powered hacksaw. The hand-held hacksaw took average of 46.33 seconds and 83.67 strokes to cut while pedal powered hacksaw took average of 33.67 seconds and 63.00 strokes (Figs. 6-7). The powered hacksaw was 12.66 seconds faster with lesser stroke of 20.67.

### 3.3. Cutting of $\phi$ 32 mm Circular Steel Pipe of 1 mm Thickness Using Hand-Held Cutting and Pedal Powered Hacksaw Method

Cutting of  $\phi$ 32 mm circular steel pipe of 1 mm thickness was done using hand-held cutting method and pedal powered hacksaw. The hand-held hacksaw took average of 54.00 seconds and 92.00 strokes to cut while pedal powered hacksaw took average of 43.67 seconds and 72.33 strokes (Figs. 6-7). The powered hacksaw was 10.33 seconds faster with lesser stroke of 19.67.

### 3.4. Cutting of $\phi$ 25 mm Circular Steel Pipe of 1mm Thickness Using Hand-Held Cutting and Pedal Powered Hacksaw Method

Cutting of  $\phi$ 25 mm circular steel pipe of 1 mm thickness was done using hand-held cutting method and pedal powered hacksaw. The hand-held hacksaw took average of 47.00 seconds and 82.33 strokes to cut while pedal powered hacksaw took average of 33.67 seconds and 64.33 strokes (Figs. 6-7). The powered hacksaw was 13.33 seconds faster with lesser stroke of 18.00 strokes.

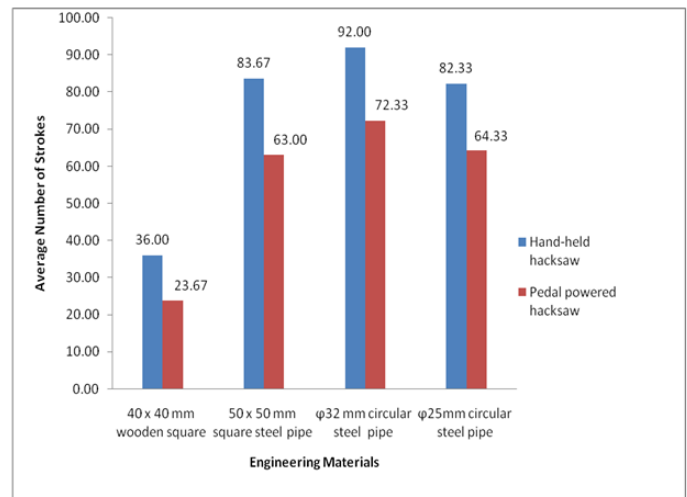


Figure 6: Average number of strokes required to cut different materials

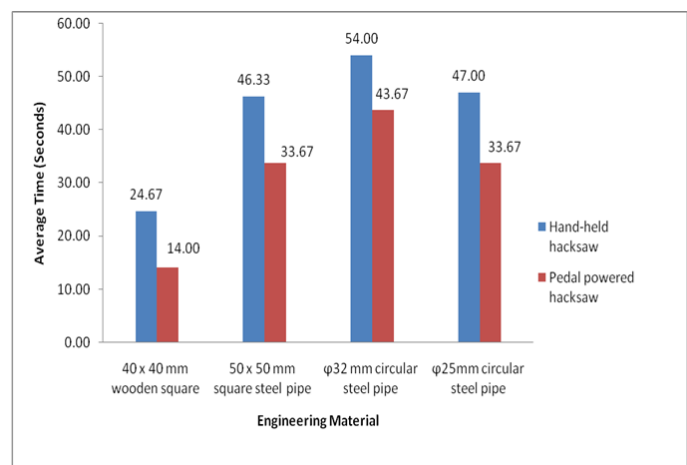


Figure 7: Average time required to cut different materials

The hand-held hacksaw required 52.1, 32.8, 27.2 and 28.0% more strokes than pedal powered hacksaw in cutting 40 x 40 mm solid wooden square, 50 x 50 mm steel square pipe,  $\phi$ 32 mm circular steel pipe and  $\phi$ 25mm circular steel pipe, respectively (Table 3). The percentage deviations of stroke are significant.

Table 3: Percentage deviation of hand-held hacksaw stroke from pedal powered hacksaw stroke

Engineering material	Percentage deviation (%)
40 x 40 mm wooden square	52.1
50 x 50 mm steel square pipe	32.8
$\phi$ 32 mm circular steel pipe	27.2
$\phi$ 25mm circular steel pipe	28.0

The hand-held hacksaw required 76.2, 37.6, 23.7 and 39.6% more strokes than pedal powered hacksaw in cutting 40 x 40 mm solid wooden square, 50 x 50 mm steel square pipe,  $\phi$ 32 mm circular steel pipe and  $\phi$ 25mm circular steel pipe, respectively (Table 4). The percentage deviations of time are significant.

Table 4: Percentage deviation of hand-held hacksaw time from pedal powered hacksaw time

Engineering material	Percentage deviation (%)
40 x 40 mm wooden square	76.2
50 x 50 mm metal square pipe	37.6
$\phi$ 32 mm circular metal pipe	23.7
$\phi$ 25mm circular metal pipe	39.6



#### 4. CONCLUSION

A pedal powered hacksaw was modelled and fabricated using a scrap bicycle. The pedal powered hacksaw is 63.9% efficient and the cost of fabrication is thirty-seven thousand and five hundred naira (₦37,500). Performance evaluation carried out on some engineering materials (40 mm x 40 mm solid wooden square, 50 x 50 mm square steel pipe,  $\phi 25$  mm and  $\phi 32$  mm circular steel pipes of 1 mm thickness) showed that there were significant time saving in use of pedal powered hacksaw when compared to hand-held cutting method. The fabricated pedal powered hacksaw can be used in remote areas where there are no electricity supplies and it does not require special technical knowledge compared to manual hand cutting method and other electric machines (such as portable hand cutting machine and band saw machine) used for cutting engineering material. Also, the pedal powered hacksaw, a technological innovation, will save the environment from dumping of scrap bicycles and impact positively on cardiorespiratory, physical and mental fitnesses of the operator.

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#### CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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