Design and fabrication of a shredder

A E Oladejo*1, S I Manuwa2,4 and T B Onifade*3

1,2Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure. Nigeria
3Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.
4Department of Agricultural and Biosystems Engineering, Landmark University, Omu Aran, Nigeria
Email: tbonifade@lautech.edu.ng

Abstract. Over the years, the excessive use of agro-chemicals (pesticides and fertilizers) have adverse effect on the soil health and lead to declining of crop yields and quality of products. The shredding of twigs will provide an alternative for the use of agro-chemicals. For this to happen, the twigs will first be shredded into small bits making it ready for transportation and further processing. This necessitated the development of a shredder machine. The machine consists of three-phase electric motor, bearings, structural frame, cutters, hopper, shredding unit, discharge chute, belt drive and shaft. Four cutters are mounted on the shaft, which rotate by a belt drive. The power from the electric motor is transmitted to the cutter shaft through a belt drive. Cut is made inside the shredding unit due to the effect of tensile, friction and impact effect in shredding process. The twigs get shredded and the small bits are collected at the discharge chute of the shredder. The performance of the machine was evaluated and test results showed that there was a correlation between the weight of the shredded twigs and the shredding time. The shredding operation was done at 4 different time intervals (4 minutes, 8 minutes, 12 minutes and 16 minutes) with the same weight of twigs (40 kg) and the weight of small bits of twigs collected increases with time. The machine is user friendly and recommended for farmers and medium scale entrepreneurs.

1. Introduction
Agricultural production leaves considerable amounts of agricultural waste. Some of it is recycled into the agricultural production as fertilizer, while large amounts remain unused and in many instances pose a disposal problem. It has been realized that large quantity of agricultural waste remains being unutilized because of handling, storage and management related difficulties. The reasons are their low bulk density, large area/volume for storage. The farmers on the field burn most of these wastes after the harvesting of crops. Thus the agricultural waste burning phenomena is being repeated every year. In order to use these wastes for some economical benefits, so the necessary of such machine was felt to utilize all kinds of agricultural waste after shredding, which could be economical and practicable [1].

A variety of crops are cultivated in Nigeria. But after harvesting them the crop residues are either burnt out or thrown as waste without taking into consideration their nutritive value. With the
increase in population our compulsion is not only to stabilize agricultural production but also to increase it further in sustainable manner. Hence, a natural balance needs to be maintained at all cost for existence of life and property [2]. At present, twigs, coconut or palm leaf stalks, or other waste raw materials from production operated by community enterprises and factories are processed in many ways for agricultural uses. This not only helps reduce storage space, but also transforms garbage into value added products for community enterprises or business operators [3].

Survey was carried out through product study, market study, literature review and user study etc. In the beginning the crop residues were cut manually by the farmers after harvesting their crop. Traditional method of shredding the dried stems by putting them in a cloth bag and rolling over it with a bullock cart or thrashing it on the ground was also a boring job. This technique did a good job of chopping the stems (avoiding the painful fingers problem), but we still had to pick up the cloth now and then to turn it to avoid it from tearing out since the stems used to come out there by tearing the cloth. Also the stems were thrashed by bamboos by the farmers which served as a Herculean Task. Thus these are not reliable method for shredding crop residues to obtain good compost in appropriate duration of time. Thus it brings to our knowledge that the traditional methods are not sufficient and satisfactory for chopping the crop residues. Due to these manual processes, some major problems are identified and to over-come these problems, the idea of shredder machine to chop twigs to produce effective and efficient fertilizer was developed [2].

The Shredding machine can be used in a commercial as well as helping point of view for farmers by setting up small business, providing organic compost to various other farmers which due to their poverty think of taking a drastic and senseless decision of committing suicide as they are poor and are not self-sufficient to make their own organic fertilizer and neither are able to buy chemical fertilizers to increase and meet their minimum crop yield demand, thereby providing a helping hand to farmers to meet their never ending demand of fertilizer. The farmers will benefit in the use of shredder machine to chop twigs for compost production and effectively use it for sustainable agricultural production. The objective of this work is to fabricate and evaluate the multipurpose shredder.

2. Materials and Methods
2.1. Design Considerations
Material selection based on availability, durability, cost and ease of fabrication were considered. The efficient performance of the machine and acceptability of the machine to the farmers and households who would be the user of the machine was profound to be the main focus. The cost of the machine is relatively low so that farmers can easily purchase. Also, it is easy to operate, even by non-educated farmers, if it needs to be. The following advantages were obtained from the design considerations: reasonable design, compact structure, safe and durable, only one motor drive, low noise, easy operation, compact layout, stable work, convenient to move, low energy consumption, high production efficiency, reasonable price. The design considerations can be summarized thus:

i. Availability of materials of construction: Easily sourced components were used in construction of the machine. For the ease of future fabrication and development, the materials used in the fabrication are easily sourced such as metal sheet, angle bar, band saw, etc., which are readily available in the country.

ii. Affordability: Use of cheap and yet effective materials and components as a means of achieving cost effectiveness in the course of project thereby making the machine relatively cheap and affordable.

iii. Ease of operation: With the provision of electric motor of suitable horse power to drive the machine, hence the machine will be easier for the operator to operate and understand.

iv. Strength and durability: For better service life of the device, materials of considerable strength and durability were adopted.

v. Feed and product sizes: The type of materials to be shredded is small branches of trees of at most 25 mm diameter. The moisture content of the twigs is also at reduced moisture content for effective and efficient shredding.
2.2. **Design Analysis**
The following are the design procedure and calculation of how the operation parameters of the parts of the machine are determined.

2.2.1. **Design of cutter**
Cutter Specifications
- Outer diameter of cutter = 150 mm
- Inner diameter of cutter = 25 mm
- Number of teeth on cutter = 40
- Thickness of cutter = 15 mm

2.2.2. **Design of hopper**
Volume of the hopper = \( \frac{1}{3} (A_1 + A_2 \sqrt{A_1 + A_2}) h \) \hspace{1cm} (1)

Where, 
- \( A_1 \) = Area of top base (cm\(^2\))
- \( A_2 \) = Area of bottom base (cm\(^2\))
- \( h \) = Height of hopper

\( A_1 = 45 \text{ cm} \times 30 \text{ cm} = 1350 \text{ cm}^2 \)
\( A_2 = 40 \text{ cm} \times 15 \text{ cm} = 600 \text{ cm}^2 \)
\( h = 15 \text{ cm} \)

\[ \text{volume of the hopper} = \frac{1}{3} (1350 + 600 + \sqrt{(1350 + 600)}) \]

Volume of the hopper = 871 cm\(^3\)

**Volume of twig in the shredding chamber:**
\[ \text{volume of twigs} = \pi r^2 h \] \hspace{1cm} (2)

Where 
- \( r \) is the radius of the twig (cm)
- \( h \) is the height of the twig (cm)
- \( r = 1 \text{ cm}, h = 3 \text{ cm} \) and \( \pi = 3.142 \)

\[ \text{volume of twig} = 3.142 \times 1^2 \times 3 = 9.5 \text{ cm}^3 \]

No of twig to fill the hopper = \[ \frac{\text{volume of hopper}}{\text{volume of twig}} = \frac{871}{9.5} = 92 \text{ twigs} \] \hspace{1cm} (3)

2.2.3. **Design of shaft**
*Shaft design* consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions.

**Design consideration for shaft**
The material used for shaft should have the following properties:
- It should have high strength
- It should have good machinability
- It should have good heat treatment properties
- It should have high wear resistance properties

Carbon steel is mainly used for shaft, except when high strength is required; alloy steel such as nickel, nickel-chromium or chrome-vanadium is used.

**Determination of shaft diameter**
\[ d^3 = \frac{16}{n_s} \sqrt{(k_b m_b)^2 + (k_t m_t)^2} \] \hspace{1cm} Khurmi *et. al.*[4] \hspace{1cm} (4)

Where, \( d \) = diameter of the shaft (mm)
Ss = Allowable shear stress of metal with key way = 40 × 10^6 N/m^2
M_b = maximum bending moment (Nmm)
M_t = torsion moment (Nmm)

\[ K_b = \text{combined shock and fatigue factor applied to bending moment} = 2.0 \text{ (sudden loading)} \]
\[ K_t = \text{combined shock and fatigue factor applied to torsional moment} = 2.0 \text{ (sudden loading)} \]

2.2.4. Belt design

**Speed transmission**

Velocity ratio for the belt drive is the ratio between the velocity of the driver and the driven. It may be expressed mathematically as:

\[ \frac{N_2}{N_1} = \frac{D_1}{D_2} \]

Khurmi et. al. [4]

Where:
- \( N_1 \) = Speed of the Driver (Electric motor) = 1460 r.p.m.
- \( N_2 \) = Speed of the follower (r.p.m.)
- \( D_1 \) = Diameter of the driver = 100 mm
- \( D_2 \) = Diameter of the follower = 200 mm

Therefore:

\[ N_2 = \frac{(1460 \times 100)}{200} = 730 \text{ rpm} \]

**Velocity of Belt, V**

\[ V = \frac{\pi D_2 N_2}{60} \]

Khurmi et. al. [4]

Therefore:

\[ V = \frac{\pi \times 0.2 \times 730}{60} = 7.65 \text{ m/s} \]

**Velocity ratio of a belt drive**

\[ VR = \frac{D}{d} = \frac{N_2}{N_1} \]

Where:
- \( D \) = diameter of the driven pulley in (m)
- \( d \) = diameter of the driving pulley in (m)
- \( N_1 \) = speed of the driven pulley in r.p.m.
- \( N_2 \) = speed of the driving pulley in r.p.m. (electric motor)
- \( VR \) = velocity ratio

For this design a motor speed of 1460 rpm will be used and a speed of 730 rpm will be used for the pulley attached to the shaft. A standard pulley diameter of 100 mm will be used for the driving pulley.

\[ VR = \frac{1460}{730} = 2 \]

**Centre distance from the pulley**

\[ x = \frac{d + D}{2} \]

From the equation 2.8, \( x = \frac{100 + 200}{2} + 100 \)

\[ x = 250 \text{ mm} \]

**Length of the belt**

In open belt drive system, both pulleys rotate in the same direction. The total length of the belt is given as:

\[ L = \frac{\pi}{2} (D + d) + 2x + \frac{(D-d)^2}{4x} \text{ (in terms of pulley diameters)} \]

Where \( x = \text{Centre distance from the two pulleys in mm} \)
\( D = \text{diameter of the driven pulley in mm} \)
d = diameter of the driving pulley in mm

\[ L = \frac{\pi}{2} (200 + 100) + 2(250) + \frac{(200 - 100)^2}{4(250)} \]

Length of the belt is 982 mm

Angle of contact

\[ \theta = (180 + 2\alpha) \frac{\pi}{180}\text{ rad}. \] (10)

Where, \( \theta \) = Angle of contact

\[ \alpha = \sin^{-1} \frac{R - r}{2x} \] (11)

\[ \alpha = \sin^{-1} \frac{100 - 50}{2(50)} = 5.74 \]

Where R = radius of the driven pulley in (m)
\( r = \) radius of the driving pulley in (m)
\( x = \) centre distance from the pulley in m
\( \alpha = \) wrap angle of the smaller pulley

\[ \theta = (180 + 2(5.74)) \frac{\pi}{180}\text{ rad.} \]

\[ \theta = 3.35 \text{ rad} \]

Power transmitted by the belt

The belts are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds (Fig 2). The amount of power transmitted depends on the following factors:

i. The velocity of the belt

ii. The tension under which the belt is placed on the pulleys

iii. The arc of contact between the belt and the smaller pulley

iv. The conditions under which the belt is used

Tension in the belt

\[ 2.3 \log \frac{T_1}{T_2} = \mu \theta \quad \text{Khurmi et. al. [4]} \] (12)

Where \( T_1 = \) tension at the tight side of the belt (N)
\( T_2 = \) tension at the slack side of the belt (N)
\( \mu = \) coefficient of friction between the belt and pulley = 0.25
\( \theta = \) angle of contact in degree

\[ \log \frac{T_1}{T_2} = \frac{\mu \theta}{2.3} = \frac{0.25 \times 3.35}{2.3} \]

\[ \frac{T_1}{T_2} = 2.32 \]

\[ T_1 = 2.32T_2 \]

\[ \text{Power transmitted}, P = (T_1 - T_2)v \quad \text{PSG [5]} \] (13)

\[ T_1 - T_2 = \frac{P}{V} \]

\[ T_1 - T_2 = \frac{5 \times 746}{7.65} = 487.58N \]

Substituting equation (2.14) into equation (2.15)

\[ 2.32T_2 - T_2 = 487.58N \]

\[ T_2 = 371.5N \]
\[ T_1 = 2.32 \times 371.5 = 861.7N \]

**Figure 1.** The isometric and orthographic views of the shredder

**Figure 2.** Cutter assembly on the shaft
(a) Testing of the Machine
The machine was tested using a 5 hp, single-phase electric motor as a source of power. The testing of the machine was to verify the noise and efficiency of the shredder. A known mass of the twig product was fed into the hopper and the time taken to shred the sample was recorded. The weight before shredding and weight of the twigs after shredding was also recorded during the assessment process. The test was done 4 times and average readings were recorded.

3. Results and Discussion
The developed model of the shredder machine as shown in fig 1 was subjected to performance test. The shredder machine performance was measured using the total quantity of small bits chopped for different time durations. The machine has the capacity to cut 40-50 kg of twigs to small bits per hour considering allowances such as machine setup time, jamming of cutter assembly whereas manually to cut twigs require many labour and very time consuming. The test was conducted on the shredder developed to ascertain its suitability and function ability.

The graph below shows weight of small bits (kg) vs time (min). The graph clearly shows that the amount of small bits collected with respect to time. The test was conducted at 4 different intervals of times.

![Graph showing weight of small bits vs time](image)

**Figures 3.** The graph of weight of small bits (kg) vs time (min)

The figure 3 above shows the relationship between the weight of small bits collected at the bottom of the collector after the shredding operation and time taken. The shredding operation was done at 4 different intervals of time. The results obtained at different time were used to plot the graph. The weight of powder collected increases as the time increases.

4. Conclusions
Proper evaluation of the design is performed and created something even better instead of simply manually operated operations. Finally, we conclude that the machine is better option to use by the farmer instead of manual operations of chopping twigs. The machine is designed taking into
consideration the various demands of farmers and other customers. Since this machine is made for small businessman or for farmers, therefore the work carried out by this machine is less. The capital required for purchasing the bigger size crop residue shredding or chopping machine is very high and also the substitute way of using chemical fertilizers is also very costly.

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