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DESIGN ANALYSIS OF A MODULAR GRASS SHREDDING MACHINE

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Abstract:

Shredding machines are usually used to reduce the size and shape of materials. In this research work, a modular grass shredding machine is designed mainly to aid the production of organic manure. The main components of the machine include feed hopper, multipurpose petrol engine, main frame, main shaft, adjustable screw, sieve mechanisms, shredding disc, etc. The design of the shredding machine includes the determination of the volume of the hopper unit and the force and power that could shred the grass and the selection of a convenient material for the construction of the individual units. Two conceptual designs were considered and decision matrix was used to select the best concept for detail design analysis. The results of the design analysis showed that a shredding force and power of 197 N and 2 hp were required for the operation of the machine. More so, torque of 2.4625 Nm, volume of feeder hopper 0.026 m³, volume of sieve compartment of 0.0567 m³ and area of sieve compartment of 0.1134 m² were established. Besides, the value of maximum bending moment obtained was relatively small as compared to the length of the belt and the diameter of the shaft. This implies that the shaft will retain its ability to function optimally under the applied total transverse load.

Keywords: Design Analysis; Shredding Machine; Grass; Shredding Power; Shredding Force

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1.0 Introduction

Nigeria is a state of forests, savannas, and desert (Sanni *et al.*, 2010). Although, part of the territory was once covered with dense tropical rainforests but continuous deforestation, bush burning and continuous cropping led to grassland covering large portion of its territory (Schmoldt *et al.*, 1999; Sanni *et al.*, 2010). Also, excessive use of agro-chemicals like pesticides for controlling of grasses and inorganic fertilizer to replenishment of soil fertility may affect the soil health and lead to declining of crop yields and quality of products (Trabzon, 2008). Hence, a natural balance needs to be maintained at all cost for existence of life and property. The obvious choice would be judicious use of agro-chemicals and application of naturally occurring material in farming systems such as organic manure from anaerobic digestion. Application of organic manure for farming purpose is a system, which avoids or largely excludes the use of synthetic inputs (such as fertilizers, pesticides, hormones, feed additives etc.) and to the maximum extent feasible relies upon crop rotations, crop residues, animal manures, off-farm organic waste, mineral grade rock additives and biological system of nutrient mobilization and plant protection (Somasundaram, 2007; Somasundaram, 2008; Ratkocivh *et al.*, 2013).

However, to prepare organic manure mechanically using grasses, a shredding machine which accelerates the process of composting by increasing the surface area for aerobic degradation thereby reducing the time to obtain the compost from usually a period of four months to one month is required. A shredding machine is designed to reduce large solid material objects into a smaller volume, or smaller pieces (Orhorhoro *et al.*, 2016). Mechanical shredding is the process of transferring a force amplified by mechanical advantage through a material made of molecules that bond together more strongly, and resist deformation more, than those in the material being crushed (Clark, 1985; Arunk *et al.*, 2016). Thus, for shredding process to be successfully carried out, the crushing materials must possess a better strength and toughness than the materials to be crushed. Thus, shredding process work by mainly holding the material between two parallel or tangent solid surfaces, and in the process sufficient force is apply to bring the surfaces together to generate enough energy within the material being crushed so that its molecules fracture, or change alignment in relation to (deformation), each other (Lodhi, 2013).

Furthermore, in the past and even until now, cutting of grasses is carried out manually with the use of cutlass. This method of manual cutting is time consuming because human effort is

needed for the cutting. Also, large quantities of grasses for composting and animal feed might not be achieved in a short possible time, thus, the mechanical means of shredding via the use of machine is urgently needed. Although, some researchers in the past have developed grass cutting machine but a lot still need to be done especially for further reduction in size for composting. For instance, Karthik *et al.* (2016) in their research work fabricated grass cutting machine with rotary blades by using solar energy. The solar energy is trapped in the photovoltaic cell to generate electricity and placed such that to absorb high intensity from sun and it will incline at 45° . By considering ground clearance they can adjust the height of grass. Also, Praful *et al.* (2016) in their research work developed a manually operated grass cutter with spiral roller blades due to spiral blades increases the efficiency of cutting. For adjusting the height reel cutter is component placed on grass cutter. In same line, Pankaj *et al.* (2016) prepared manually handle device. However, their grass cutter will give much more physical exercise to operator and it will easily handle. Considering limitations such manually handle device, continuous adjustment of height reel cutter, etc., recorded in the aforementioned research work, the redesign of grass shredding machine is necessary. More so, a machine that can produce a smaller size shredded grass to enhance fast decomposition via composting will be a welcome development. According to Orhorhoro *et al.* (2017), smaller size biodegradable materials decomposes faster when mixed with bio-digester effluent as compared to larger biodegradable materials.

2.0 Materials and Methods

2.1 Conceptualization

Two conceptual designs were considered. In design concept one (1), the main components of the machine include frame, feed hopper, V-belt, pulley(s), shaft, bolts, bearings, grinding chamber, electric motor etc. The main function of the frame is to support, guide and hold in accurate alignment all the moving members of the operating machine. The frame was constructed from angle bar to give rigidity and stability that will withstand load and vibration. The discharge end is located at the end of the feed hopper which is attached to the shredding chamber. The machine is powered by an electric motor via belt drive connected to the main shaft that turns the grinder. The hopper into which the grass is fed is located at the top of machine. Figure 1 shows the isometric view of design concept one. The main components of the machine in design concept two include feed hopper, multipurpose petrol engine, bolts and nuts, V-belts, pulley, receiver/container, main frame, bearings, shaft housing, main shaft, adjustable screw, sieve mechanisms, clamp nut, clamp bolt, tyre, handle, shredding disc,

discharge vent. The hopper into which the grass is fed is located at the top of machine. The design of the shredding machine includes the determination of the volume of the hopper unit and the force and power that could shred the grass and the selection of a convenient material for the construction of the individual units. Also, the machine is powered by a two-stroke engine via the belt drive connected to the main shaft in the shredding chamber. The shredding chamber is made with thick rigid mild steel plate. All the joint parts are welded with arc welding except the side which is bolted for the purpose of easy coupling and uncoupling. A smaller plate was used to cover the front side of the shredding chamber. This fixture is created for easy maintenance of the shredding blades and the housing. It is equally constructed in such a way that stuck grass wastes are easily removed. A sieve mechanism with perforation of 3 mm is attached to the shredding chamber with the help of cam drive and follower mainly to regulate the size of successfully shredded grass wastes sample. Figure 2 shows the isometric view of design concept two.

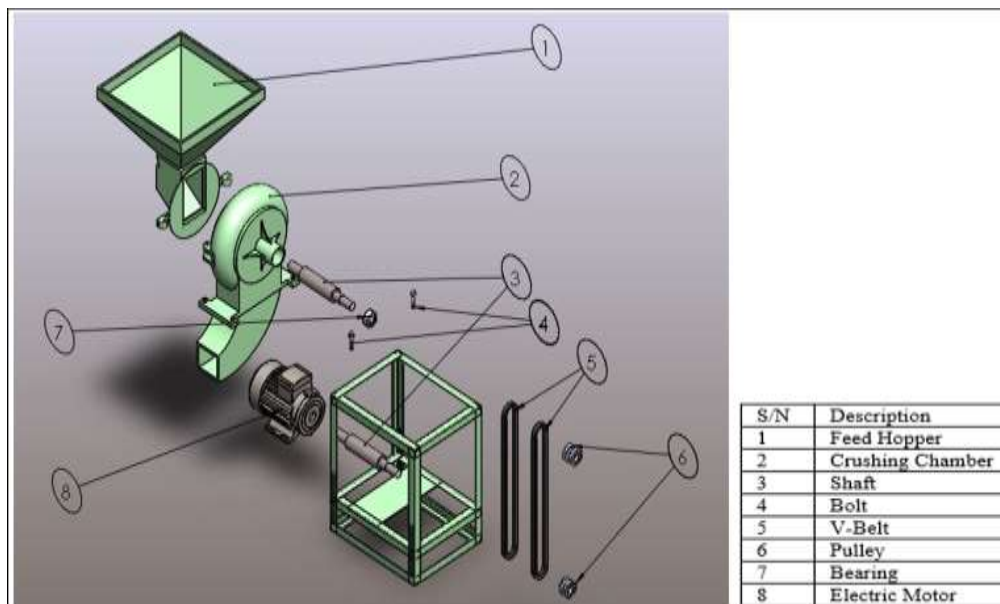
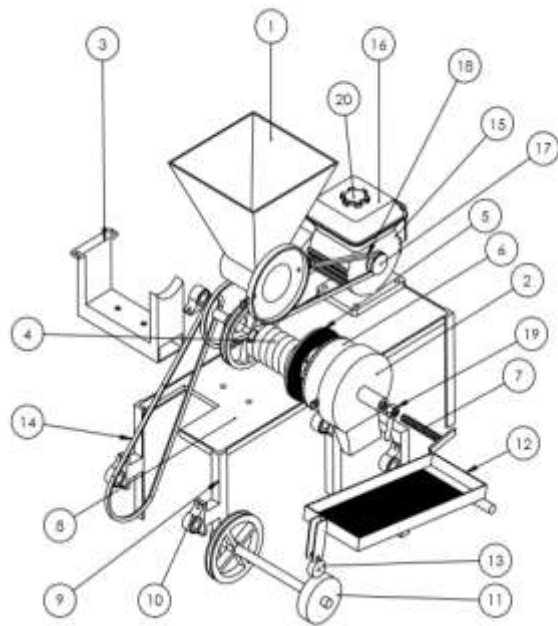


Figure 1. Isometric view of design concept one



S/N	PART LIST	QUANTITY
1	Hopper	1
2	Discharge Vent	1
3	Hopper Stand	1
4	Conveyor (worm) Shaft	1
5	Stationary Grinding Disk	1
6	Grinding Disk	1
7	Adjustable screw	1
8	Base	1
9	Stand	1
10	Pillow Bearing	6
11	Cam Drive	1
12	Sieve	1
13	Follower	1
14	Cam Drive Belt	1
15	Two Stroke IC Engine	1
16	Engine Tank	1
17	Engine Pulley	1
18	Engine Belt	1
19	Adjuster	1
20	Tank Cover	1

Figure 2. Isometric view of design concept two

Decision matrix was used to select the best concept for detail design analysis. Details of the decision matrix used are shown in Table 1. After careful analysis of the criteria options with respect to the generated concepts, design concept two (2) with the highest score of 80.5 was considered the best design concept for detail design analysis.

Table 1. Decision matrix used to rank developed conceptual designs.

Criteria	Weight	CONCEPT 1		CONCEPT 2	
		Rating	Score ⁽¹⁾	Rating	Score ⁽¹⁾
Functionality	3.5	6	21	7	24.5
Safety	3	9	27	9	27
Cost	2.5	15	20	8	20
Maintenance	1	7	7	9	9
Total	10		75		80.5

2.2 Materials Selection for the Shredding Machine

Table 2 shows the components parts, material used and justification.

Table 2. Components Parts, Material Used and Justification

S/N	Component part	Material used	Justification
1	Hopper	Mild steel sheet	<ul style="list-style-type: none"> ❖ Readily available ❖ It undergoes plastic deformation ❖ Does not wear easily
2	Shaft	Stainless Steel	<ul style="list-style-type: none"> ❖ Does not wear easily during operation ❖ High tensile strength ❖ Ability to resistance corrosion ❖ Ability to withstand shear force and compressive force.
3	Frame (Base)	Mild steel angle bar	<ul style="list-style-type: none"> ❖ Readily available ❖ It is plastic ❖ Does not wear easily
4	Sieve	Mild steel plate	<ul style="list-style-type: none"> ❖ Readily available ❖ Does not wear easily
5	Shredding disc	Stainless steel	<ul style="list-style-type: none"> ❖ Toughness and strength ❖ Corrosion resistance
6	Bearing	High Carbon Steel	<ul style="list-style-type: none"> ❖ Resistance to wear and corrosion, hard, tough and has high strength
7	Pulley	Cast Iron	<ul style="list-style-type: none"> ❖ Tough, hard, low cost and has high strength
8	Angle bar	Mild steel (Low carbon steel)	<ul style="list-style-type: none"> ❖ Ability to withstand shear force and compressive force.
9	V-belt	Fibre reinforced rubber	<ul style="list-style-type: none"> ❖ It is strong, flexible and durable ❖ It has a high coefficient of friction
10	Metal Sheet	Stainless Steel	<ul style="list-style-type: none"> ❖ Ability to resist corrosion. ❖ At high temperatures it prevents scale and maintains strength. ❖ Hygienic to use, because it easy to clean.

2.3 Detailed Design Analysis of the Shredding Machine

The area and volume of the sieve compartment were calculated to know the quantity of shredded grass that can be accommodated. Equation (1) and Equation (2) were use to calculate the area and volume the sieve compartment.

$$A_{sc} = LW \quad (1)$$

$$V_{sc} = LHW \quad (2)$$

To know the torque required to shred the dried grass samples, it became necessary to determine the shredding torque. The shredding torque is given by Equation (3)

$$T_s = F_s r \quad (3)$$

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

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad (4)$$

Length of the belt that passes over the driver in one minute is given by;

$$\pi d_1 N_1 \quad (5)$$

Similarly, length of belt that passes over the follower in one minute is given by,

$$\pi d_2 N_2 \quad (6)$$

Since the belt passes over the driver in one minute is equal to the length of the belt that passes over the follower in one minute

Therefore;

$$\pi d_1 N_1 = \pi d_2 N_2 \quad (7)$$

The required velocity is given by Equation (8)

$$V = \frac{\pi DN}{60} \quad (8)$$

The power requires to shred the grass is given by Equation (9)

$$P = FV \quad (9)$$

where,

$$F = ma \quad (10)$$

The centre to centre distance between driver and driven pulley is given by Equation (11)

$$C = 2D_1 + D_2 \quad (11)$$

The belt length can be obtained as given by Equation (12)

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{D_1 + D_2}{4C} \quad (12)$$

The lap angle is expressed as follow (Khurmi and Gupta, 2005):

$$\alpha = 180 \pm 2 \sin^{-1} \left(\frac{D_2 - D_1}{2C} \right) \quad (13)$$

The belt tension can be calculated as follow (Khurmi and Gupta, 2005):

$$2.3 \log \left(\frac{T_1}{T_2} \right) = \mu \alpha \quad (14)$$

The diameter of shaft was determined using Equation (15)

$$d^3 = \frac{16}{\pi S_s} \sqrt{(K_b M)^2 + (K_t T_d)^2} \quad (15)$$

Also,

$$T = \frac{60PK_L}{2\pi N} \quad (16)$$

For suddenly applied load (heavy shock), the following values are recommended for K_b and K_t
 $K_t = 1.5$ to 3 (Khurmi and Gupta, 2013)

The bearing parameters for bearing selection was calculated from Equation (17)-Equation (20)

$$L_{10} = \frac{60 \times L \times N}{10^6} \quad (17)$$

$$F_e = (x C_r F_r + C_t F_t) S_f \quad (18)$$

$$\frac{f_t}{x f_r} \leq 0 \quad (19)$$

$$C = L_{10}^{1/K} \cdot F_e \quad (20)$$

3.0 Results and Discussion

Table 3 shows the results of detailed design of the grass shredding machine for composting. The shredding force and power were calculated as 197 N and 2 hp respectively. Torque of 2.4625 Nm, volume of feeder hopper 0.026 m³, volume of sieve compartment of 0.0567 m³ and area of sieve compartment of 0.1134 m² were established. The speed of the driven and driver of 480 rpm, and 1440 rpm were obtained. The required velocity and the ratio of driver speed to driven speed were calculated as 3.7704 m/sec and 3:1. The length of belt and the distance between driver pulley and driven pulley were determined as 1.014 m and 0.25 m. Moreover, angle of lap of 3.044, belt tension of 2171.513 N, radial force of 2961.154 N and 789.641 N were established.

Table 3. Results of detailed design

S/N	Parameters	Unit	Calculated Data
1	Volume of Feeder Hopper (V _p)	m ³	0.026
2	Area of sieve compartment (A _{sc})	m ²	0.1134
3	Volume of sieve compartment	m ³	0.0567
4	Shredding Force	N	197
5	Shredding Torque	Nm	2.4625
6	Speed of the driver	Rpm	1440
7	Speed of the driven	Rpm	480
8	Ratio of driver speed to driven speed	-	3:1
9	Required velocity	m/s	3.7704
10	Shredding power	Hp	1
11	Distance between driver pulley and driven pulley	M	0.25
12	Length of belt	M	1.014
13	Angle of lap	Rad	3.044
14	Tension generated	N	2171.513
15	Radial force acting on the shaft	N	2961.154
		N	789.641
16	Life of the bearing	Hour	18,000 ≤ 22,000
i.	Shaft diameter 2961.154N		
ii.	Basic Dynamic Load of Bearing	N	33900
iii.	Basic Static Load of Bearing	N	22400
iv.	Basic Dynamic Life of Bearing	Milli rev	1900.8
v.	Radial Factor	-	1

vi.	Thrust Factor	-	0
vii.	Rotational Factor	-	1
viii.	Mass of Bearing	Kg	0.34
ix.	Bearing thickness	Mm	24
x.	Bore Diameter	Mm	62
xi.	Designation	-	4305ATNP

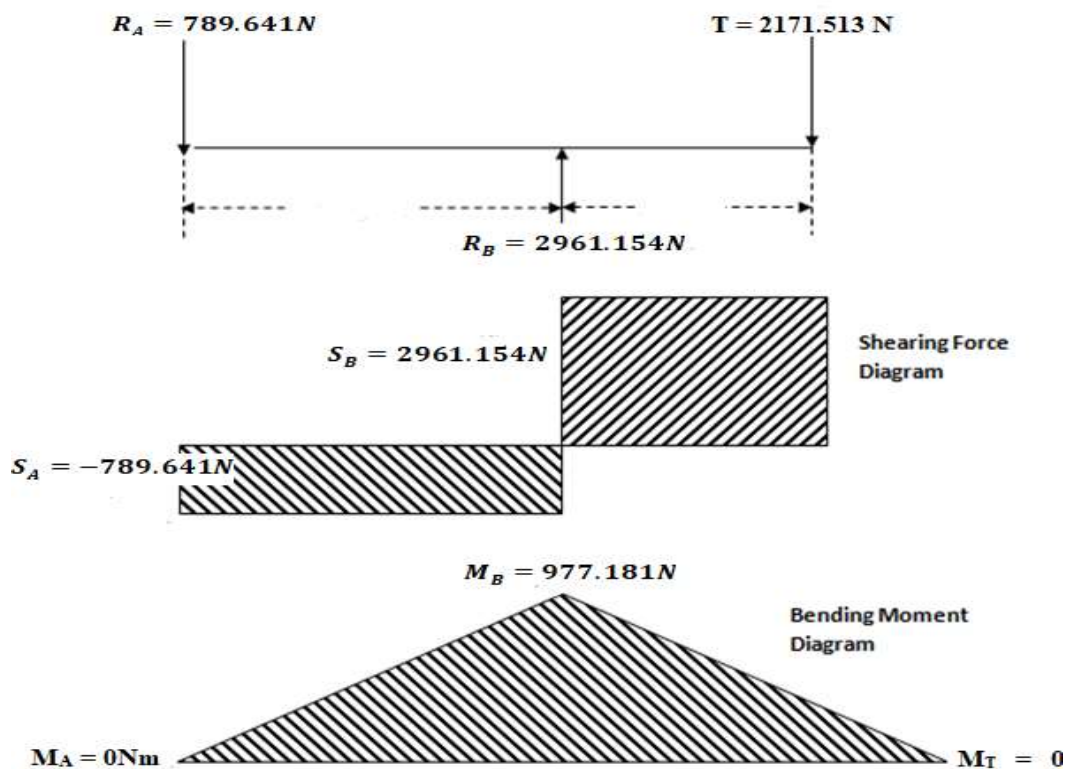


Figure 3. Shearing and bending moment diagram

The bending moment at bearing A and Bearing B were obtained as zero (Figure 3). Also, maximum bending moment obtained was negligible relative to the length of belt and the diameter of the shaft. This implies that the shaft will retain its ability to function optimally under the applied total transverse load. The shaft is fixed between the bearings on both ends which are in turn fixed to the frame. Hence the axial loading on the shaft may be considered negligible. Thus, the shaft dimensions and material were selected to provide optimum function under the expected axial, transverse and torsional loading condition. A basic dynamic load and basic static load of 33900 N and 22,400 N were calculated for. The calculated basic dynamic load was used to select a double groove ball bearing of shaft diameter of 25 mm. Cost and maintenance were the major factors considered in selecting the bearing. The machine configuration is shown in Figure 4-Figure7.

Moreover, unlike the design of Pankaj *et al.* (2016) that the grass cutting machine is a manually handle device, in this new design, the machine is powered by a two-stroke engine via the belt drive connected to the main shaft in the shredding chamber and this will enhance fast shredding of grasses, thus, producing more shredded grass for composting. Also, a minimum power is required for shredding of grasses and with grinding disc as the shredding element, a smaller size fine grain of grass sample will be produced as compared to the research work of Praful *et al.* (2016) that make use of a manually operated grass cutter with spiral roller blades and Karthik *et al.* (2016) that make use of rotary blades using solar energy as source of power.

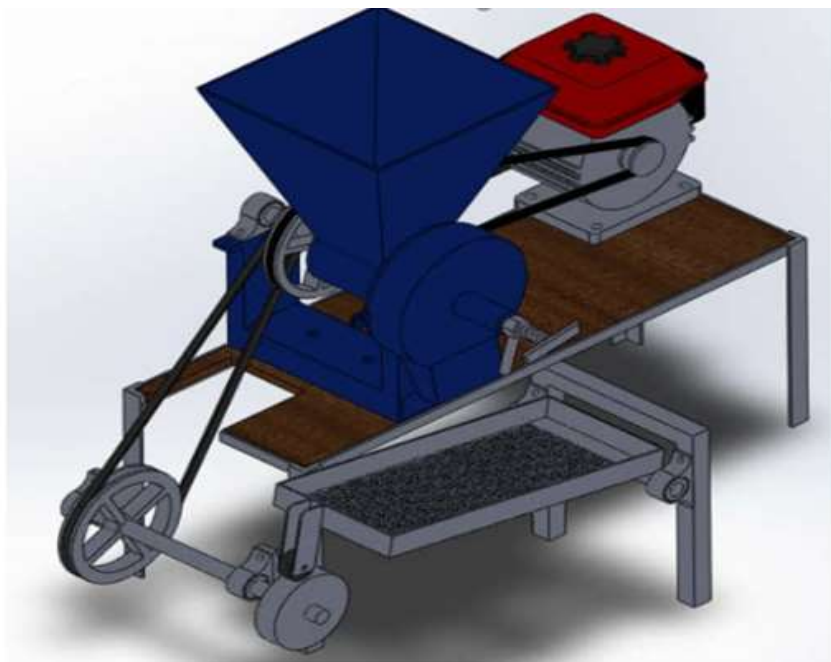
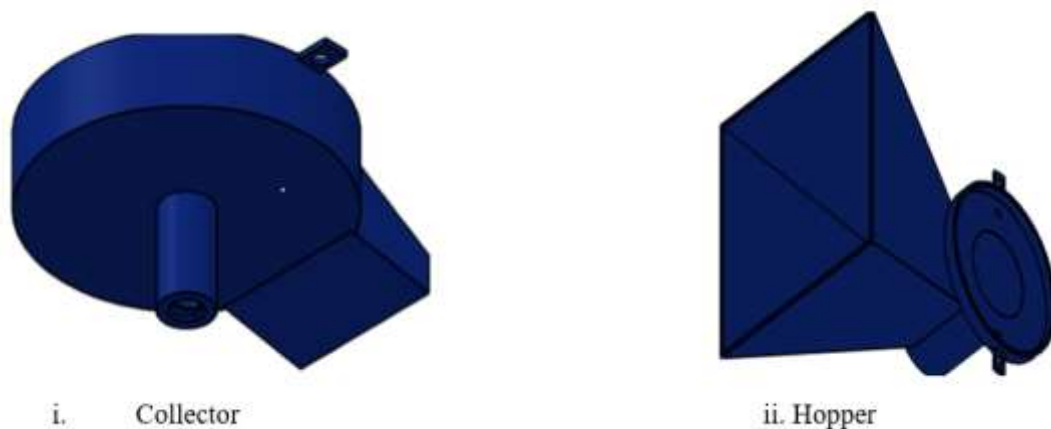


Figure 4. Isometric model view of the machine



i. Collector

ii. Hopper

Figure 5. Isometric view of (i) collector and (ii) Hopper

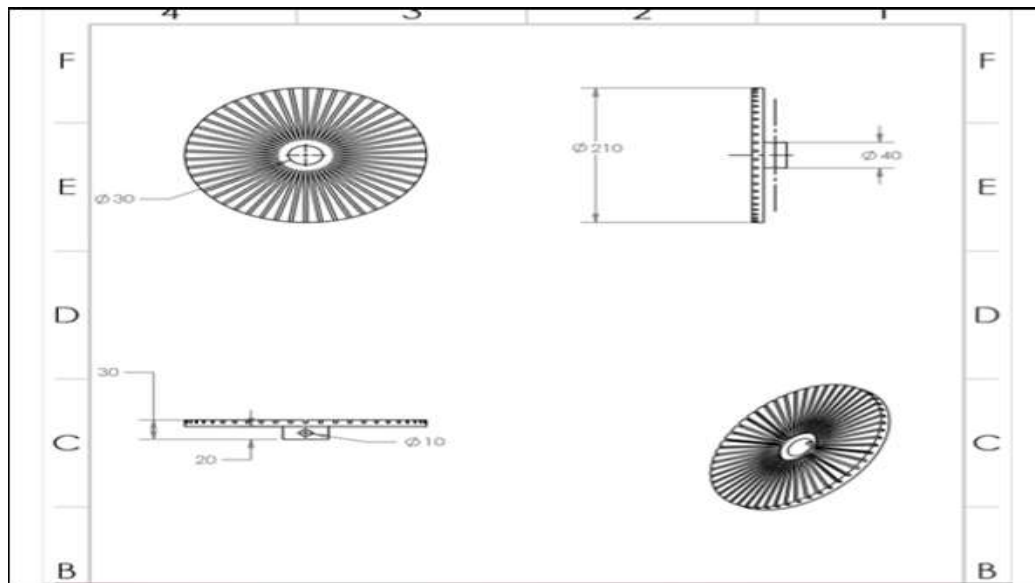


Figure 6. Orthographic view of grinding disc

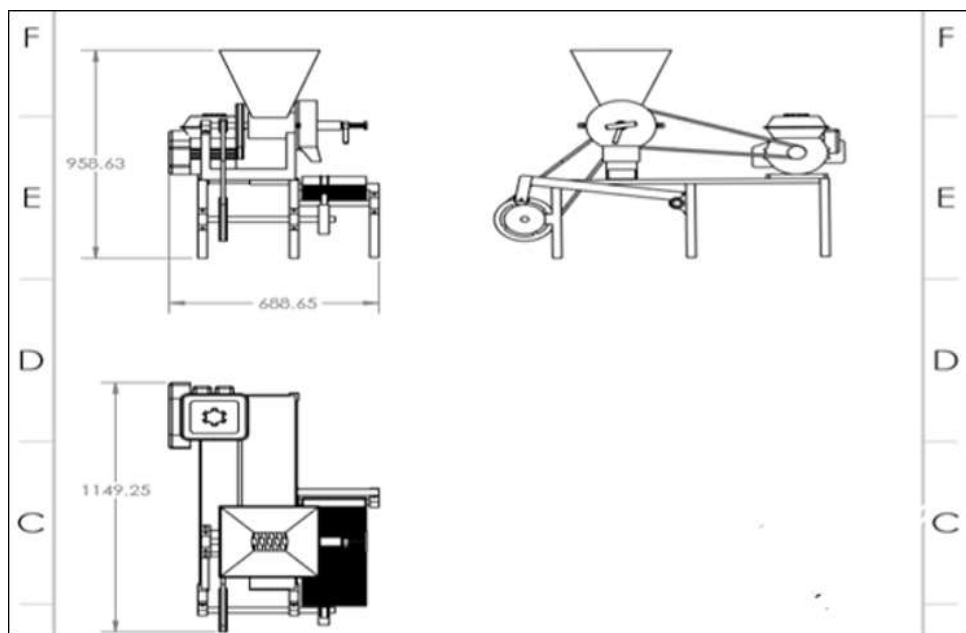


Figure 7. Orthographic view of shredding machine

4.0 Conclusion

In this research work, a modular grass shredding machine was successfully designed. Analysis was carried out to determine the best design values of parameters such as torque, shredding force and power, shaft diameter, sieve compartment volume, etc. The results obtained show that driven and driver speed of 480 rpm, and 1440 rpm were required. Also, the required velocity and the ratio of driver speed to driven speed were calculated as 3.7704 m/sec and 3:1. The shredding force and power were calculated as 197 N and 2 hp respectively. Torque of

2.4625Nm, volume of feeder hopper 0.026m³, volume of sieve compartment of 0.0567m³ and area of sieve compartment of 0.1134m² were established.

Nomenclature			
α	Angle of wrap of an open belt	L	Belt length (m)
α_1	Angle of lap for driver pulley (rad)	m	Mass (kg)
α_2	Angle of lap for driven pulley	M	Bending moment (Nm)
μ	Coefficient of friction	N_1	Speed of the driven (rpm)
a	Acceleration (m/s ²)	N_2	Speed of the driven (rpm)
A_{sc}	Area of sieve compartment (m ²)	P	Power required (watt)
A_{sc}	Volume of sieve compartment	r	Radius from axis of rotation to point of application of force (m)
c	Centre to centre distance between driver pulley and driven (m)	T	Tension in the tight side of the belt (N)
C	Basic dynamic load (N)	T_1	Tension in the tight side of the belt (N)
d_1	Diameter of the driver (m)	T_2	Tension in the slack side of the belt (N)
d_2	Diameter of the follower (m)	T_s	Required torque (Nm)
F_e	Equivalent dynamic load (N)	V	Required velocity (m/s)
f_r	Radial factor	V_{sc}	Volume of sieve compartment (m ³)
F_s	Shredding force (N)	W	Width (m)
f_t	Thrust factor	x	Speed factor
h	Height (m)		
K_L	Load factor		

References

- Arunk, A.1., Arun, P.U., Febins, P.M., Basil, B., Sreeej, T.S., Rinto, K.A. (2016). Design and Analysis of Organic Waste Crushing Machine. *International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)*, 3(1), pp.24-30
- Clark, R.W. (1985). Works of Man: History of Invention and Engineering, From the Pyramids to the Space Shuttle. 1st American Edition. 8"x10" Hard cover ed., Viking Penguin, Inc., New York, NY, U.S.A., pp. 352, ISBN 9780670804832
- Khurmi, R. J., and Gupta, J. K. (2013). Machine Design, Eurasia Publishing House (pvt) Ltd, New Delhi.
- Lodhi, G. (2013). Operation and Maintenance of Crusher House for Coal Handling in Thermal Power Plant. *International Journal of Mechanical Engineering and Robotic Research*, 2(4)
- Orhorhoro, E.K., Ikpe, A.E., Tamuno, R.I. (2016). Performance Analysis of Locally Design Plastic Crushing Machine for Domestic and Industrial Use in Nigeria. *European Journal of Engineering Research and Science*, 1(2), pp. 26-30
- Orhorhoro E.K., Ebunilo P.O.B., and Sadjere E.G. (2017). Design of Bio-Waste Grinding Machine for Anaerobic Digestion (AD) System. *European Journal of Advances in Engineering and Technology*, 4 (7), pp.560-568

Ratkocivh, N., Horn, W., Helmus, F.P., Rosenberger, S., Naessens, W., Nopens, I., Bentzen, T.R. (2013). Activated sludge rheology: A critical review on data collection and modelling. *Water Res.*, 42, pp.463-482

Sanni L.O., Aiyelaagbe O.O. Idowu M.A., Olayiwole I.O., and Dipeolu Adebawale A.A. (2010). Sustainable organic agriculture development in 21. Willer, H. and L. Kilcher, 2009. *The world of organic Africa*. MRC/08/F07/p33 Policy Brief No. 2.

Schmoldt D.L., Peterson D.L., Keane R.E., Jm lenihan D., Mckenzie, D.R., and Weise-Sandberg D.V. (1999). Assessing the effects of fire disturbance on ecosystems: a scientific agenda for research and management. United States Department of Agriculture, Forest Service, General Technical Report PNW-GTR-455, pp. 104.

Somasundaram, E. (2007). Effect of Agro-Industrial Wastes on Soil Properties and Yield of Irrigated Finger Millet, 3, pp. 153-156

Trabzon, M. (2008). Heavy metal adsorption onto agro-based waste materials, 157, pp. 220-229