"DESIGN, ANALYSIS AND FABRICATION OF BALER MACHINE FOR THE COMPACTION OF SOLID WASTE"

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ABSTRACT: Increased economic growth and urbanization developed in the generation of a large amount of waste. Municipal Solid Waste, Electronic waste is currently the largest growing stream in the world which is shipped to developing countries for recycling.

This project deals with the recycling processes, that involves the separation of waste based on the type. In this process, waste is gathered from household, industry, office, commercial outlets etc., are collected and stored. The waste occupies large space due to the irregular shape and creates pollution to the environment. For the solid waste management, the first step to consider is, the storage of waste properly which can be done by compressing waste in the baler machines in large quantities. The compression of the waste is usually handled by the recycling industries; the initial steps of collection of waste involves transportation and manpower but this can be reduced by implementing the method of Baling household-wise/community-wise, henceforth, the occupancy of space in the vehicles can be reduced to a great extent also, the pollution at the dump yards can be reduced.

The aim of this project is to create a small size Baler machine which can be installed at every house or at community level so that the compression of waste can be done at the initial step of waste collection. The results are based on the Compressor box assembly (Baler Box). Solid dry waste (Paper, plastic) material is inserted in to the Baler box in order to compress the waste with the applying load of 3000 kg on compressor plate, and further it is converted in to the bales.

Keywords: *Mini-Baler Machine, Baler Machine, Solid Waste Compaction, Paper waste Compaction, Plastic waste Compaction, Mechanical machinery.*

1. Introduction: The major challenge to the authorities of both small and large cities in developing countries is Solid waste. This is mainly due to the increasing generation; the solid waste also increases around the world. Solid waste is an unwanted or useless solid material generated from combined residential, industrial, and commercial activities.

Solid waste management is the process of collection, transportation disposal of solid waste in a systematic, economic, and hygienic manner. 'OR' Solid-waste management is the process of collection, treating, and disposing of solid material that is discarded because it is of no use.

The project deals with designing, analysis and fabrication of Baler Machine for the compaction of solid waste. It is a portable Mini-Balor machine and can carry from one place to another place.

1.2 Balor Machine role for decreasing the landfill area:

1.2.1 Baler Machine: A Baler Machine is a device which compress the solid waste by application of Ram force into rectangular bales and that can be transferred for recycling industries. Baler is designed for similar or dissimilar wastes, and it is very useful machine for space minimization due to solid waste.

1.3 Working Mechanism: The working mechanism of the design of mini size Baler machine consists of a Baler Box with a lid above it, and below is a pressing plate to press the solid dry waste which is paper and plastic, inside the box, the Compressing rod (Ram) connected to the plate and on other end of the Compressing rod (Ram) is connected to the arm which is connected to the Hydraulic Jack, it is responsible for the force to be applied on the Ram. The force to the ram is developed by applying the force applied on the handle downwards of the Hydraulic Jack. This is how the force is transferred from hydraulic jack to the Ram and to the pressing plate where the solid dry waste is subjected to press inside the Baler Box and obtains the shape of the rectangular box. By this way we can manage the solid waste in an organized bale in order to avoid heaps of solid waste gathering and can reduce the landfill area and also can reduce the environmental pollution to certain level.

Figure 1.2 Compressed Bale

2.1 Background:

2.1.1 The Origin of Waste:

The journal discusses about, the waste is anything we want to get rid of. Waste can be defined as materials that are not prime products for which the generator has no further use in terms of his/her own purposes of production, transformation, or consumption, and of which he/she wants to dispose. Wastes may be generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities [4].

Figure 2 Types of Solid Wastes [5]

Wastes from different fields are originated related mining, agriculture, forestry, Industry, Household, commercial and government bodies, construction demolition and waste water treatment.

2.1.2 Sources, composition and characterization of the solid waste:

Solid waste has become the most challenging issue to the environment. For handling and management of the solid waste, the quantity and composition are determined appropriately. In the figure given below gives the overall composition and classification of the solid waste management.

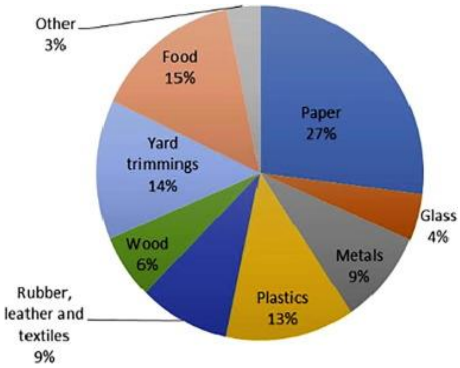


Figure 4 Composition and classification of solid [1].

Different solid wastes are generated from variable sources of human and domestic activities in day-to-day life. The major solid wastes generated are mainly from households (55-80%) are reported and also followed by market or commercial areas (10–30%). Remaining solid wastes which are generated from industries, streets, institutions and many other sectors are highly heterogeneous in nature, and due to the variable physical and chemical characteristics depending upon their original sources, the composition is yard waste, paper waste, plastics, metals, wood, rubbers, paints, bottles, leathers, batteries, inert materials, textiles, glass waste, demolishing and construction materials as well as many others are very difficult to classify. So, there must be a proper treatment of a solid waste by sorting and separating in using traditional methods and technical methods in order to get the quality of the separated waste fraction for any potential utilization by solid waste managements [1].

2. Literature Review:

2.1 Solid waste management in landfill area:

Solid Waste Management: Principles and Practice (Authors Townsend, Timothy G.) Landfills are an important part of solid waste management systems, serving as a primary means of disposing of waste that cannot be recycled or otherwise diverted from the waste stream. However, the management of landfills can present a number of environmental and health challenges, which must be carefully addressed to ensure that these facilities are operated in a safe and sustainable manner. One of the key issues associated with landfill management is the potential for environmental contamination. When waste is buried in landfills, it can release a range of harmful substances, including methane gas, leachate, and other contaminants. These substances can pose a risk to both the environment and human health, and must be carefully managed to prevent their release into the surrounding ecosystem [2].

2.2 Mini-Baler Machine:

Agricultural Baler (Author: Arsene Roth) This research relates to an agricultural baler that includes substantially a pickup element, a conveyor which transports a harvested product stream picked up from a field, and a transferring device which conveys the collected product stream in direction toward a bailing chamber. In the known balers the transferring device is composed of several profiled disks which are fixedly mounted on a cylinder, the baler has sensors which are formed as pilotable sensing brackets located between the pressing chamber for detecting the harvested product stream over the Width, an evaluating device connected. With the sensors, and adjusting means connected with the evaluating device. Basically, this kind of device can only be used in making bales in agricultural field [3].

3. METHODOLOGY:

3.1 Methodology and Design:

In this project, methodology is developed for estimating the solid waste management into different categories.

The following steps are undertaken for the project are as follows:

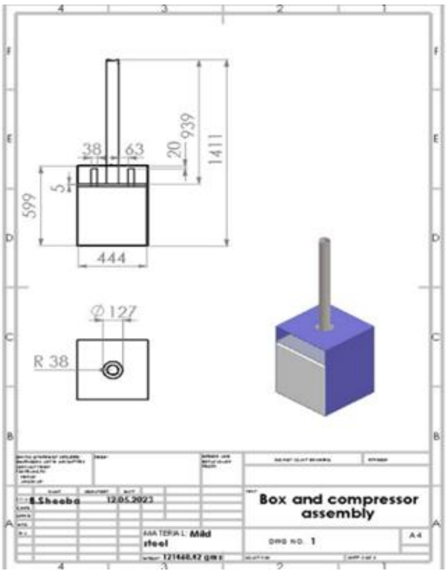


Figure 3.1 Baler box assembly

3.2 Project Design: The project is design is mainly based on stress and deflection on the Box and compressor assembly (Baler box assembly).

3.2.1 Stress under load:

According to the midline plate theory, it was originally derived for isotropic plates using equilibrium considerations. The material which is used for compression is assumed to be homogeneous and isotropic. The amount of deflection and stress a compression plate of known geometry will deflect under the specified load and distribution.

The designing is based on the main components of Baler box assembly. They are:

- **The compression plate dimensions are:** Square Plate of 444 × 444 mm and 5 mm thickness

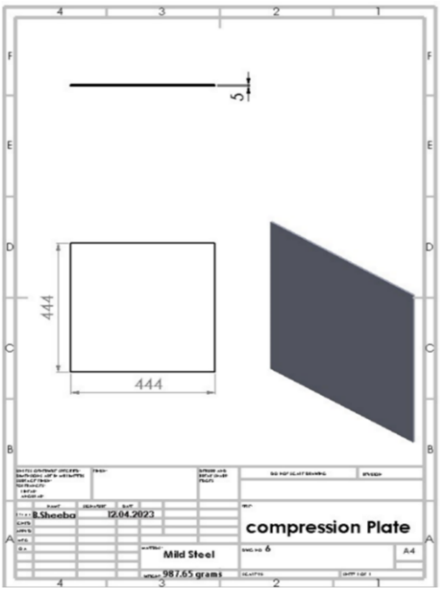


Figure 3.2 Part Diagram of a compression plate

❖ **Compression Plate Rod dimensions:**

- The dimensions of the compression rod are its length is 940 mm, 72 mm diameter and 2 mm thickness.

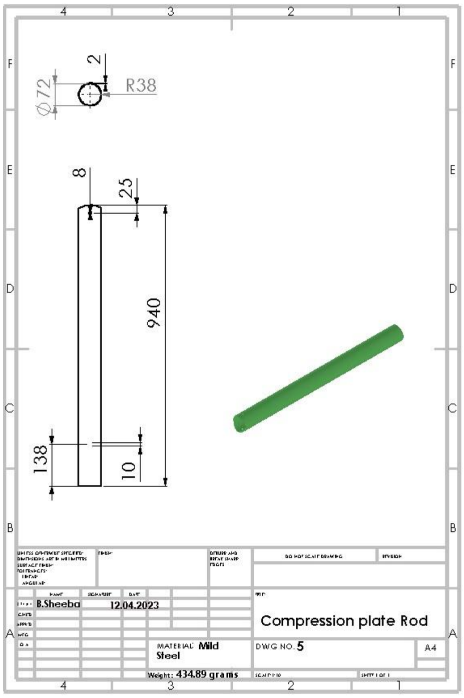


Figure 3.3 Part diagram of a compression plate rod

❖ **Baler Box dimensions are:**

- Square Box of 452 × 452 mm.
- Height is 609 mm
- Thickness is 5 mm

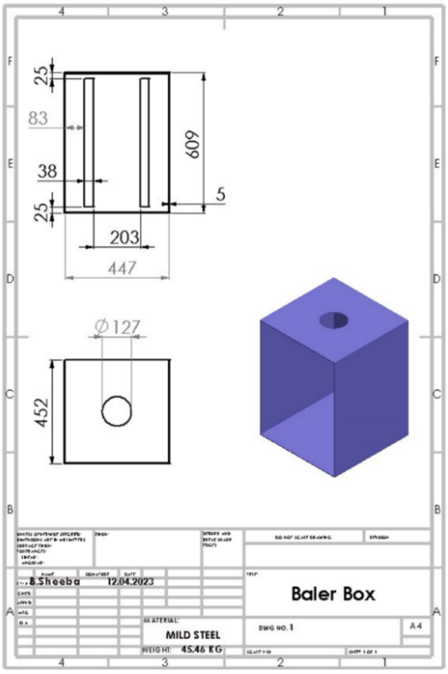


Figure 3.4 Part Diagram of Baler box

The maximum stress on compression plate can be calculated by using the formula given as:

$$\boldsymbol{\sigma_{max}} = \frac{3W(1+\mu^2)}{2\pi t^2}\left(\ln\frac{L_e}{r_0} + 0.6159\right) \rightarrow (1)$$

Where:

$$\mathbf{L_e} = \sqrt[4]{\frac{Et^3}{12(1-\mu^2)k}}$$

Deflection:

$$y_{max} = \frac{-W}{8kL_e^2}$$

Where:

W = Total load (Force) (lbs)

μ = Poison's ration

E = Modulus of Elasticity (lb/in^2)

D_o= Diameter where loading applied (in)

r_o= Radius of compression lid rod (in)

t = thickness of the compression lid rod (in)

k = Foundation modulus ($lb/length^3$)

σ = Stress, (lbs/in^2)

$\mathbf{L_e}$ = Effective length of a compressive plate ($lb/inch^3$)

y_{max} = Deflection (in)

- **Considering the plastic properties:**

Young's Modulus for plastic is
E = 1.08 G Pa = $\mathbf{108 \times 10^{7}}$ N/m²
Poison's Ratio (μ) = 0.499
k =Foundation modulus = Force/length³
(Force =3 ton =3000 kg
Length of the Compression lid rod = 37" =0.939 m)
(k=$\frac{\mathbf{3000}}{(\mathbf{0.939})^{3}}$ = 3623.62)

$$\mathbf{L_e} = \sqrt[4]{\frac{\mathbf{108 \times 10^{3} \times (2 \times 10^{-3})}}{\mathbf{12 \times (1-(0.499)^{2}) \times 3623.62}}}$$

$$\therefore \mathbf{L_e = 0.28518} \text{ N/m}^2$$

Substituting the $\mathbf{L_e}$ value in the equation (1)
W = Total force =3000 kg
t = thickness of the compression lid rod = $\mathbf{2 \times 10^{-3} m}$
$\mathbf{r_\circ}$ = radius of the compression lid rod= 0.0381 m

$$\boldsymbol{\sigma}_{\mathbf{max}} = \frac{\mathbf{3000(1+(0.4.99)^{2})}}{\mathbf{2 \times 3.14 \times (2 \times 10^{-3})}} \left(\mathbf{ln}\frac{\mathbf{0.28518}}{\mathbf{0.0381}} + \mathbf{0.6159}\right)$$

Therefore,
$\boldsymbol{\sigma}_{\mathbf{max}}$ = 149.1 N/mm² is the maximum stress developed on the compression lid.

Now,

- Considering the Paper properties:

Young's Modulus for paper is
E = 2.9 G Pa = $\mathbf{29 \times 10^{8}}$ N/m²
Poison's Ratio (μ) = 0.169
k=Foundation modulus = Force/length³
(Force =3 ton =3000 kg
Length is Length of the Compression lid rod = 37" =0.939 m)
(k=$\frac{\mathbf{3000}}{(\mathbf{0.939})^{3}} = \mathbf{3623.62}$)

$$\mathbf{L_e} = \sqrt[4]{\frac{\mathbf{29 \times 10^{8} \times (2 \times 10^{-3})}}{\mathbf{12 \times (1-(0.169)^{2})3623.62}}}$$

$$\mathbf{L_e = 3.423\ N/m^{2}}$$

Substituting the $\mathbf{L_e}$ value in the equation (1)
W = Total force =3000kg
t = thickness of the compression lid rod = $\mathbf{2 \times 10^{-3} m}$
$\mathbf{r_\circ}$ = radius of the compression lid rod= 0.0381 m
$\mathbf{L_e = 3.423}$ N/m²

$$\boldsymbol{\sigma_{max}} = \frac{\mathbf{3000 \times (1 + (0.169)^2)}}{\mathbf{2 \times 3.14 \times (2 \times 10^{-3})}} \left(\mathbf{ln} \frac{\mathbf{3.423}}{\mathbf{0.0381}} + \mathbf{0.6159}\right)$$

Therefore, Maximum stress on the compression lid is:

$$\therefore \boldsymbol{\sigma_{max}} = \mathbf{1.106\ N/mm^2}$$

Now, on an average Poison's ratio for a Plastic material and Paper material is

$$\mu = \frac{\mathbf{0.499+0.169}}{\mathbf{2}} = \mathbf{0.334}$$

And the Average Young's modulus (E) for Plastic and Paper is

$$E = \frac{\mathbf{108 \times 10^7 + 29 \times 10^8}}{\mathbf{2}} = \mathbf{199 \times 10^7}\ \text{N/m}^2$$

On an average the value of

$$\mathbf{L_e} = \frac{\mathbf{0.28518+3.423}}{\mathbf{2}} = \mathbf{1.85}$$

Now, substituting the average values for both Plastic and Paper material which are used for compression is assumed to be homogeneous and isotopic.
For finding the maximum stress on the compression lid we have,

$$\boldsymbol{\sigma_{max}} = \frac{\mathbf{3W(1 + \mu^2)}}{\mathbf{2\pi t^2}} (\mathbf{ln} \frac{\mathbf{L_e}}{\mathbf{r_0}} + \mathbf{0.6159})$$

But we know

$$\therefore \boldsymbol{L_e = 1.85\ N/m^2}$$

Now substituting the $\mathbf{L_e}$ value to find the maximum stress.
Then we get,

$$\boldsymbol{\sigma_{max}} = \frac{\mathbf{3000 \times (1 + (0.334^2))}}{\mathbf{2 \times 3.14 \times (2 \times 10^{-3})^2}} (\mathbf{ln} \frac{\mathbf{1.85}}{\mathbf{0.0381}} + \mathbf{0.6159})$$

Hence, the maximum stress on the compression plate is:

$$\therefore \boldsymbol{\sigma_{max}} = \mathbf{1.034\ N/mm^2}$$

(Or)

$$\boldsymbol{\sigma_{max}} = \mathbf{1.034}\ \text{MPa}$$

Therefore,

The material taken for the project is Mild Steel. So, the yield strength of Mild Steel is 250 MPa. Hence, the maximum stress obtained is less than 250 MPa. So, Compression lid is in safe condition to attain the stress developed due to the given load.

Now the Deflection:

$$y_{\mathbf{max}} = \frac{\mathbf{-W}}{\mathbf{8kL_e^2}}$$

$$y_{\mathbf{max}} = \frac{\mathbf{-3000}}{\mathbf{8 \times 3623.62 \times (1.712)^2}}$$

Therefore, maximum deflection on the compression plate is:

$$\therefore y_{\mathbf{max}} = \mathbf{-0.0353\ m}$$

4.1 Finite Element Analysis:

4.1.1 Stress and Deformation Analysis: Static Structural Analysis has been considered in order to find the stresses and deformed state of the Baler box assembly.

- From the below figure 4.1 gives the data about the equivalent stresses, when the force applied is 3 ton (29421 Newtons). Then the values of the equivalent stress observed as:
- The maximum stress is 85.805 MPa.
- The minimum stress is 5.8391x10^-10 MPa.

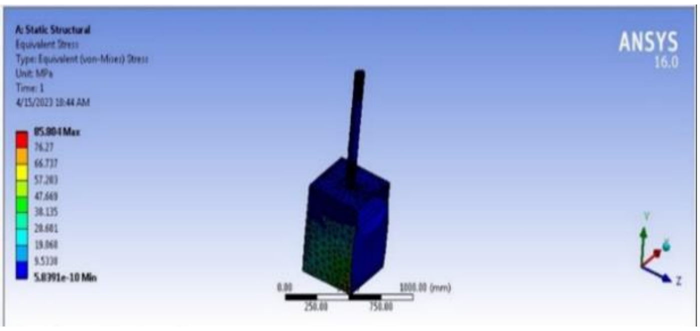


Figure 4.1 Equivalent Stress analysis

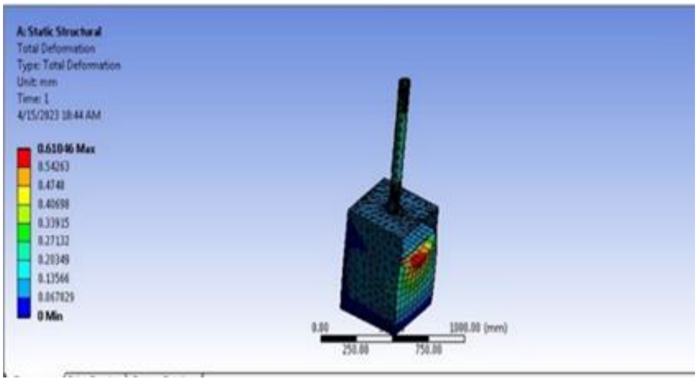
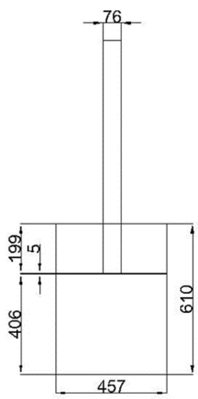


Figure 4.2 Analysis on deformation

- ❖ From the below figure 4.2, the deformation after applying 3 ton (29421 Newtons). Then the values of the deformed values are observed as:
- Maximum Deformation is 0.61046 mm.
- Minimum Deformation is 0.

5.1 Compression calculation of a Baler box Assembly: The Mini-Baler design is based on Baler box, Compression plate with compression rod attached. The overall volume of the Baler box is 127,425,600 mm³

Total Available Baler box volume (T) for inserting Solid waste material is 457x457x406 = 84,950,400 mm³, and the depth of the Baler box is 457 mm. The compression plate is of thickness 5 mm.



Total Volume of the Baler box is 127,425,600 mm³.

Available volume of the Baler box to insert Solid waste is 84,950,400 mm³.

Depth of the Baler box is 457 mm.

Figure 5.1 First Stage Before Compression

❖ In first pass - The volume available for the insertion of Solid waste is 84,950,400 mm³.

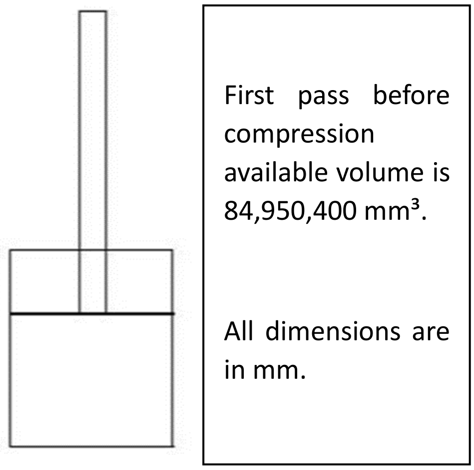


Figure 5.2 First Pass before compression

➢ When the force 3000 kg is applied on the solid waste material, the compressed volume is 21,237,600 mm³.

Figure 5.1 First pass after compression

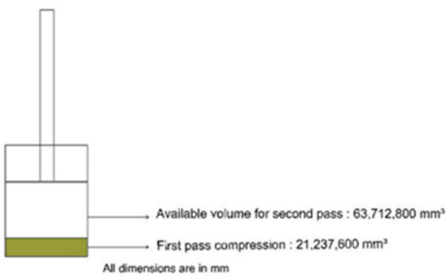


Figure 5.4 Second pass before compression

Total available volume of the Baler box is (T) = 84,950,400 mm³.After 3000 kg load applied in the first pass then compressed volume (C_1) of the solid waste mass = 21,237,600 mm³. Hence

the compression happens in the ratio of 1/4th.Then the Available volume for second pass for compression
of Solid waste material = 84,950,400 – 21,237,600 = 63,712,800 mm³.

- ❖ In second pass – The available Baler box volume for the insertion of solid waste material is = 63,712,800 mm³ (84,950,440 - 21,237,600 = 63,712,800 mm³) (Compression = 84,950,440 / 4 = 21,237,600 mm³).
- Hence, the volume of the solid waste compressed in the first pass is $C_1 =$ 21,237,600 mm³.

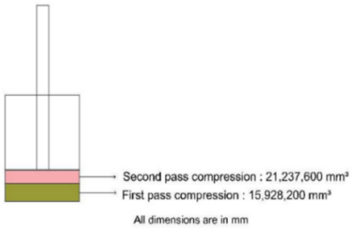


Figure 5.5 Second pass after compression

After second compression, the volume of the compressed solid waste mass (Bale) is $\mathbf{C_2}$=15,928,200 mm³ (63,712,800/4 = 15,928,200 mm³). The total compressed bale till second pass is $C_1 + C_2 = C^* = 15{,}928{,}200 + 21{,}237{,}600 = 37{,}165{,}800\ mm^3$.

- ❖ **3rd stage of compression –** The available volume for the insertion of solid waste material is 47,784,600 mm³ (84,950,440 - 37,165,800 = 47,784,800 mm³).

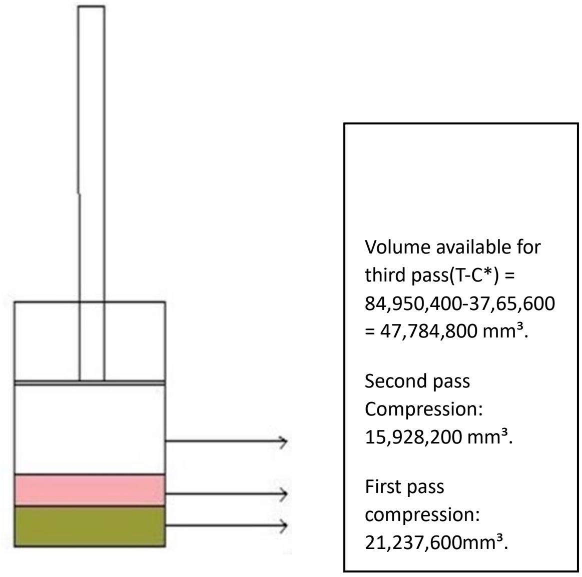


Figure 5.6 Third pass before compression

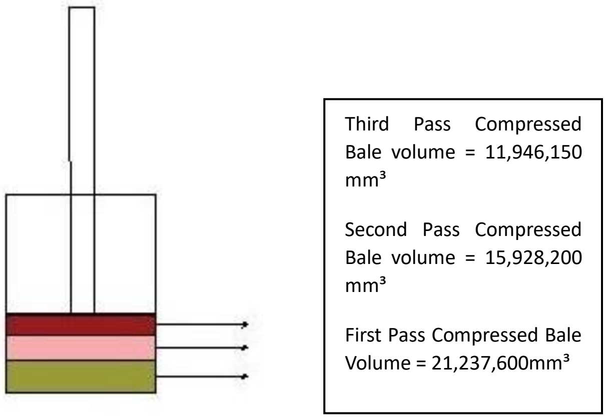


Figure 5.7 Third Pass after compression

After the force 3000 kg is applied then, the compression happens which results in reducing the volume of the bale in the ratio of 1/4 (47,784,600/4 = 11,946,150 mm³).
The volume of the compressed bale (C_3) after third pass is 11,946,150 mm³.
Therefore, the total compression from first pass to third pass is $C_1 + C_2 + C_3 = C^*$
The total compression till the third stage of compression is (21237,600 +15,928,200 + 11,946,150 = 49,111,950 mm³).
By the above calculation, the total volume compressed is = (11,946,150 +15,928,200 + 21237,600 =49,111,950 mm³).
Hence, the remained Baler box volume (T - C*=84,950,400 – 49,111,950 = 35,838,450 mm³) is left for easy handling for the removal of bale from the Baler box.

6.1 Model of a Mini Baler Machine:

The Mini Baler machine was modeled in Solid works software 2021.The construction is based on MS metal sheet of 5 mm thickness. The Baler box or Compressor box assembly which is to carry the solid waste is of 5 mm thickness sheet.

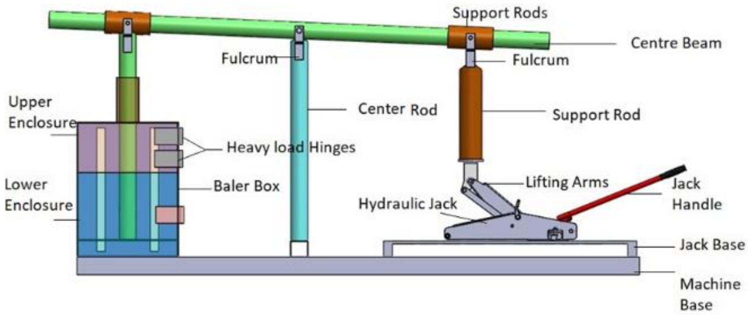


Figure 6.1 Schematic Model of Mini Baler machine

6.2 Components of Mini Size Baler Machine:

6.2.1 Baler Box
6.2.2 Centre beam
6.2.3 Centre Rod
6.2.4 Compression Lid Rod (Ram)
6.2.5 Compression plate
6.2.6 Machine Base
6.2.7 Fulcrum
6.2.8 Hydraulic Jack

6.3 Fabrication of Mini Baler Machine:

The fabrication of Mini-Baler machine is done based on the materials selected design calculations under stress and deformation conditions. Overall, the design is safe to manufacture the Mini-Baler machine under safe conditions.

6.3.1 Steps involved in the fabrication of Mini-Baler machine:

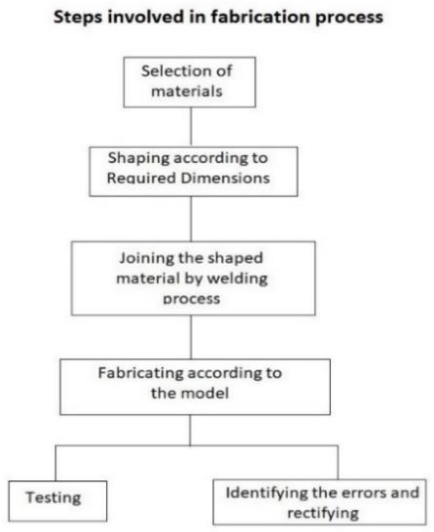


Figure 6.9 Steps involved in the fabrication of Mini-Baler machine

- Firstly, the material selected for the project is Mild Steel material because of its mechanical properties.
- The selected MS material is made to cut into required sizes, and shaped according to the dimensions required for the project.
- Then the fabrication involves in the joining of metals into required shapes like Baler box assembly and attaching the compression lid rod to the compression plate, Beam rod attached to the lid rod which also connecting to the Hydraulic Jack Rod.
- The middle rod is attached in the centre for balancing the other two attached rods for transferring the movement when the force from Jack rod is applied.
- The Hydraulic Jack is fixed at the other end base securely.

- The total machine set up is mounted on the two base bars to support the machine when applying heavy forces.
- After aligning the required components, the machine is allowed to test and identifying any kind of errors and further modified for best results.

6.4 Fabricated Mini Baler Machine:

Figure 6.10 Fabricated Mini-Baler Machine

7.1 Results and discussions: The results are based on the Compressor box assembly (Baler box). Solid dry waste (Paper, plastic) material is inserted in to the Baler box in order to compress the waste with the applying load of 3000 kg on compressor plate, and further it is converted in to the bales in the following intervals of insertions of solid waste in to the Baler box.

7.1.1 Total Compression:

The total compression from first pass to third pass is $\boldsymbol{C_1 + C_2 + C_3 = C^*}$. The total compression till the third stage of compression is (21237,600 +15,928,200 + 11,946,150 = 49,111,950 mm³).

By the above calculation, the total volume compressed is = (11,946,150 +15,928,200 + 21237,600 =49,111,950 mm³).

Hence, the remained Baler box volume (T - C* = 84,950,400 – 49,111,950 = 35,838,450 mm³) is left for easy handling for the removal of bale from the Baler box.

- ❖ Average time taken for each pass is 5 minutes.
  For total 3 passes the time taken is 3×5 = 15 minutes to complete overall Bale.
- ❖ Percentage of volume compressed = Compressed Volume / Total volume = 49,111,950 / 84,950,400 x 100 = 57.812%
  Hence, the total volume compressed is 57.812 %.

7.2 Volume of the Solid waste to the Compressed Solid waste:

Table 7.1: Relation between the given solid waste to compressed state of solid waste (Bale)

S.no	**Volume of Solid Inserted (mm^3)**	**Compressed volume of Bale (mm^3)**
1	84,950,400 / 4	21,237,600
2	63,712,800 / 4	15,928,200
3	47,784,600 / 4	11,946,150

7.2.1 Calculation of Density:

Table 7.2: Gives the Density values based on the given data Gives the Density values based on the given data

Density (d)=Mass/Volume (gm/cm^3)		
d1 (gm/cm^3)	**d2 (gm/ cm^3)**	**Total density (d) gm/ cm^3)**
500/15,944.587 = 0.03135	250/12,609.852 =0.019825	0.03135+0.019825= 0.051175

Where:

d_1**:** Density of plastic

d_2**:** Density of paper

D: Average density of plastic and paper

The density of the compressed solid waste is 0.051175 gm/cm^3.

7.4 Comparison between design calculations and finite element analysis:

From the finite element analysis:

Stress:

- When the force applied is 3 ton (29421 Newtons). Then the values of the equivalent stress observed as:
- The maximum equivalent stress is 85.805 MPa.

From design calculations of a Baler box assembly:

$$\boldsymbol{\sigma_{max} = 1.034}\ \text{MPa}$$

So, by comparing the two values, the observed stress values are less than the yield strength of Mild Steel of 125 MPa when factor of safety is 2.
(We know that yield strength of Mild Steel is 250 MPa).

7.4.1 Deformation:
From the finite element analysis,

❖ When the deformation after applying 3 ton (29421 Newtons). Then the deformed values are observed as:

- Maximum Deformation is 0.61046 mm.

From design calculations:

- The obtained deformation in design calculation of Baler box assembly is

$$\therefore y_{max} = -35.3 \text{ mm}$$

Hence, by the observed calculations, the deformation is zero which is very negligible.
Therefore, the project design is safe to undergo the applications for the given loads.

8.1 Conclusion:

- The Mini Baler Machine is designed, modelled, and fabricated in order to reduce the cost of the machine and make it available for community level application, which results in reducing the environmental pollution causing through landfill area.
- This project helps in compressing the dry solid waste into Bales at community level and transport to recycling industries for further recycling processes.
- With the application of 3000 kg load, the compressed volume of the solid waste material (Bale) is 57.812 % and the remained volume of the Baler box is 42.188 % left for clear and safe removal of compressed bale.
- Hence the compression is achieved is 57.812 %.
- It can be used at community level, where the small colonies can afford and maintain this Baler machine.
- Mini- Baler machine is available at very low cost of Rs.39,500/- compared to the market level Baler machines of very high cost of 1.5 lakh.
- The project is very cheap and best can offered able, and it is portable to carry from one place to another place.

After finding all the results based on the design analysis, Stresses and deformation values, the design is safe to undergo the applications for the given loads.

9. **References:**

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