

Finite Element Analysis and Simulation of Aluminum Can Crushing Machine

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Abstract

Original Research Article

In this 21st century, our world has been witnessing increasing consumption of Can beverages and other non-biodegradable waste materials. The ubiquitous presence of aluminum Cans in our home surroundings, on streets corners and roads, restaurants and bars, and hotels has created the need for efficient recycling and quantity reduction technologies as the adverse effects of aluminum Cans in our environment cannot be over emphasized. Consequently, this paper presents the use of ANSYS Static Structural finite element analysis (FEA) and simulation tools to evaluate stress distribution, deformation, strain energy, and crushing force during operation of the structural members of the aluminum Can Crushing Machine to enable the prediction of the machine behavior and performance. The structural analyses results showed that for the analyses performed on frame structure, half shaft-crank arm assembly, piston-cylinder assembly and machine assembly total deformation, equivalent strain, equivalent stress were observed to increase with load, while energy strain was observed to decrease with load.

Keywords: Recycling, Aluminum Can, Crushing machine, environment pollution, Finite element analysis, Structural simulation, ANSYS static structural.

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1 INTRODUCTION

In our world today a lot of human consumables come in Cans and aluminum Cans are among these (Akele & Akuete, 2022). Aluminum Cans are widely used because they are lightweight, corrosion resistance and ease of recycling. So many food and drinks are packaged in Cans especially beverages drinks. And the disposability of these Cans after using the liquid content is a major problem because after used these empty Cans are usually

stacked in bags thereby occupying the limited space. Hence the need for crushing machines to reduce the volume of Cans in the surrounding before taking them for recycling.

According to Bello et al. (2020). Most companies find it difficult to dispose of their used cans in hotels and canteens and to create enough storage space that is required. Sawant & Venkatesh (2016) stated that one problem facing the beverage industries is the problem of collapsing of aluminium



cans that leads to decrease in profit. According to Buza (2014) beverage Cans recycling is the last stage of reducing, reusing and recycling Cans into raw materials. Can crushing machine a usable machines that can help to reduce the solid wastes pollution in the environment (Kshirsagar, 2014).

This study focuses on finite element static structural simulation of aluminum Can crushing machine.

2 OBJECTIVES OF THE STUDY

The objectives of this study are:

- To model aluminum Can crushing machine using SolidWorks software.
- To perform finite element analysis on the Aluminum Can crushing machine structure.
- To simulate the aluminum Can crushing machine deformation during crushing.
- To evaluate stress, strain, and deformation characteristics.

3 LITERATURE REVIEW

Nigeria with a population of approximately 200 million with an average percent of about 60% (120 million Nigerians) constituting those who consumes Cans food items daily. One of the ways the number of Cans littering the streets can be reduced is by recycling them into new aluminum Cans or other products. And for ease of handling and transportation to recycling plants they need to be reduced to smaller sizes.

Akele & Akuete (2022a) used analytical method to determine Can crushing machine slider (piston) and crank arm relative position, velocity, acceleration, and accelerating force. The resulting slider velocity versus crank angle indicated that as the slider start from 0° to 90° the velocity increases with the increase of the crank angle before decreasing to -270° to start increasing again. The velocity curve was observed to be smooth, which is an indication of absence vibration.

Akele & Akuete (2022b) designed and fabricated Aluminum crushing machine that is based on on the slider-crank mechanism. The machine was tested and evaluated for effectiveness and the evaluation results showed power input of 382W with piston velocity of 0.813m/s, crushing rate of approximately 2 Cans/sec, 70% Can volume reduction. This present study in based on the work of Akele & Akuete (2022).

Esim & Benzer (2021) studied solid modeling and structural analysis of a foam crushing machine. Geometric optimization, linear static analysis of the machine parts maximum Von Misses stress, deformation, the factor of safety results were determined using ANSYS Workbench software. The results revealed that the material and structure of the design provide simple, reliable, and cost-effective production requirements, which are useful for industrial applications.

Bello et al. (2020) designed and fabricated a pneumatic can crushing machine that was able to reduce the volume cans by 70%. The results revealed the machine to be effective and efficient crushing between 15 and 20 cans per minute.

Sawant & Venkatesh (2016) study focused increasing the effectiveness of cans during impact loads. Study put impact loads thereby performing crash analysis of aluminium cans in order to determine how cans can withstand impact loads using FEM. All the parameters affecting can crush strength are evaluated using ABAQUS 14.0. The results revealed material thickness to be in direct proportion with the buckling strength or maximum load carrying capacity and crushing strength increases with increase in the thickness of sheet.

Rajesh et al. (2016) study entails the design and structure analysis of Can crusher. The designed Can crusher used mechanical single slider crank mechanism. The designed crusher was observed to be environmental friendly.

Gogoi et al. (2018) fabricated a Can crusher using single slider-crank mechanism that can reduce Can size by at least 70%. Two Can crushers were constructed. One is manually operated and the other a manual crusher model upgraded to an electrically operated one. Efficiencies and construction costs

comparison was carried between the two Can Crushers. The electrically operated was observed to have higher efficiency and cost.

4 METHODOLOGY

4.1 Design Considerations

In designing and construction of a dual-operated Can crusher, the following factors were put into consideration in material selection (i) availability of raw and finished materials and components, (ii) strength of materials to be used, (iii) cost of the materials, (iv) machinability of the materials, (v) power requirement, (vi) maintainability and reliability of machine, (v) ergonomics, (vi) effectiveness of the machine, and (vii) reliability.

4.2 Design Specifications

In the designing of the crusher machine certain design specifications or factors were put into consideration. They include size, operating speed, expected efficiency of machine, forces on components.

4.3 Machine Description

Designed Can crushing machine consists of:

- Hopper
- Frame structure
- Half shaft- crank assembly
- Piston-connecting rod assembly
- Fixed cylinder
- Electric motor

4.4 Geometrical Dimensions: Aluminum Can

| Parameter | Value |
|-----------------|---------|
| Can height | 124 mm |
| Can diameter | 67 mm |
| Sheet thickness | 0.12 mm |

4.5 Material Properties: Aluminum Can Material

| Property | Value |
|-----------------|------------------------|
| Material | Aluminum Alloy |
| Density | 2700 kg/m ³ |
| Young's Modulus | 69 GPa |
| Poisson Ratio | 0.33 |
| Yield Strength | 276 MPa |

4.6 Crushing Piston

| Parameter | Value |
|-------------------------|--------|
| Piston outside diameter | 68mm |
| Piston length | 150 mm |
| Piston thickness | 5 mm |
| Piston mass | 22kg |

4.7 Crushing Cylinder

| Parameter | Value |
|---------------------------|--------|
| Cylinder length | 250 mm |
| Cylinder outside diameter | 76 mm |
| Cylinder thickness | 5 mm |

4.8 Frame/Piston/Cylinder Material

| Property | Value |
|-----------------|------------------------|
| Material | Mild Steel |
| Density | 7850 kg/m ³ |
| Young's Modulus | 210 GPa |
| Poisson Ratio | 0.30 |
| Yield Strength | 250 MPa |

4.9 Governing Equations

Stress Equation

$$\sigma = \frac{F}{A}$$

Where:

σ = Stress

F = Applied force

A = Cross-sectional area

Strain Equation

$$\varepsilon = \frac{\Delta L}{L}$$

Where:

ε = Strain

L = Length

4.10 Boundary Conditions

- Cylinder fixed on frame
- Crushing piston reciprocates horizontally with compressive force

- Can is compressed between piston and inner cylinder surface
- Crushing force is applied at constant rpm

4.11 Method of Solution

SolidWorks was used to separately model the geometry of the frame structure, the half shafts and the crank arm assembly and imported into ANSYS 16.2 Workbench. ANSYS 16.2 was separately used to analyze frame structure, the half shafts and the crank arm assembly and the complete assembly. Comparative analyses were then performed using different force loadings and angular velocities with each analysis simulated to determine the effects of the loads on the assembly.

4.12 Modeling Geometries

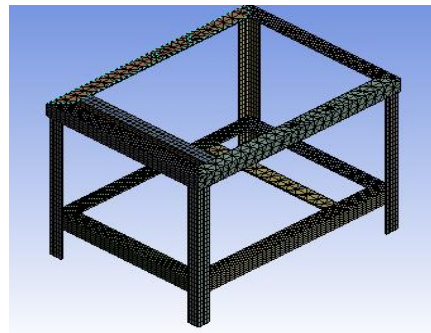
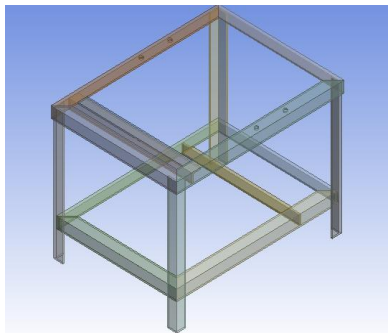


Fig 1: Frame geometry and Mesh (Coarse, Nodes – 40783, elements – 7082)

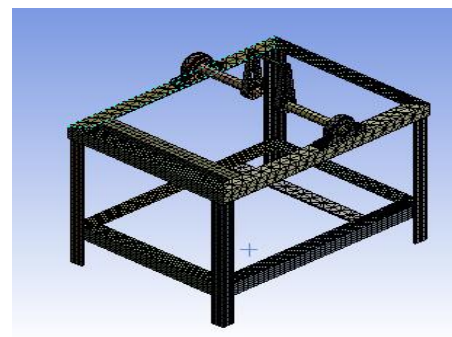
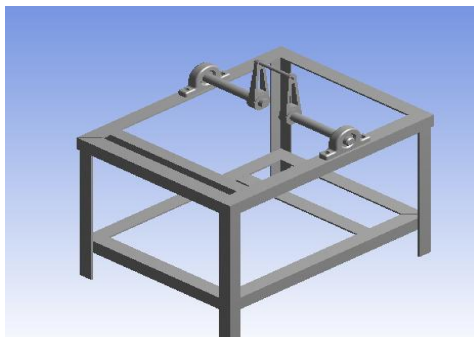


Fig 2: Shaft-crank geometry and Mesh (coarse, nodes – 45044, elements – 9226)

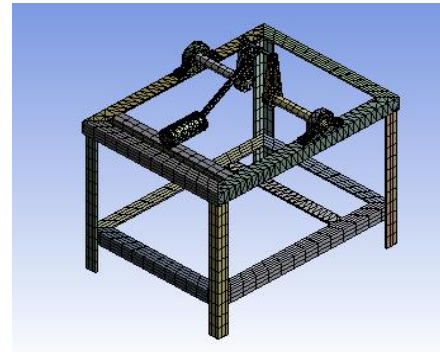
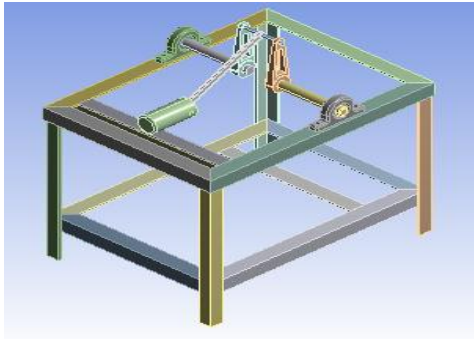


Fig 3: Assemble geometry and Mesh (coarse, nodes – 34256, elements – 13312)

5 RESULTS AND DISCUSSION

5.1 Frame Analysis

- Applied force on all four top frame members – 1580N

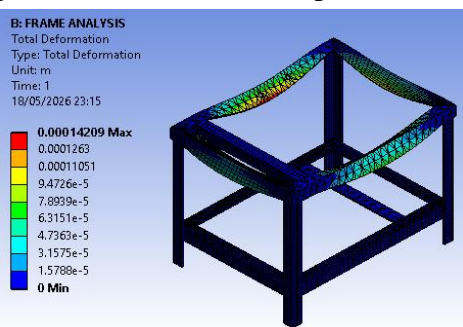


Fig 4: Total deformation

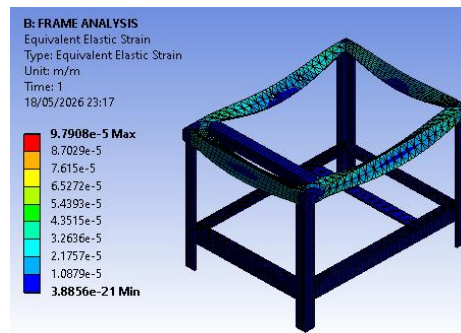


Fig 5: Equivalent strain

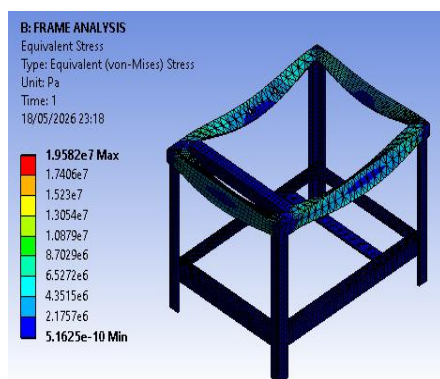


Fig 6: Equivalent stress

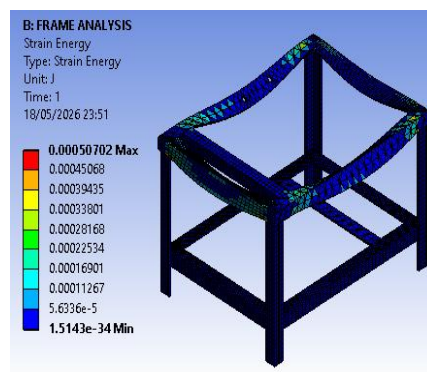


Fig 7: Strain energy

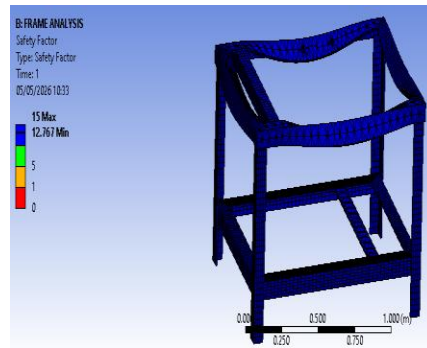


Fig 8: Safety factor

- Applied force on all four top frame members – 5000N

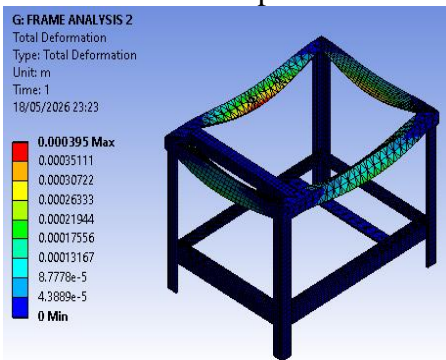


Fig 9: Total deformation

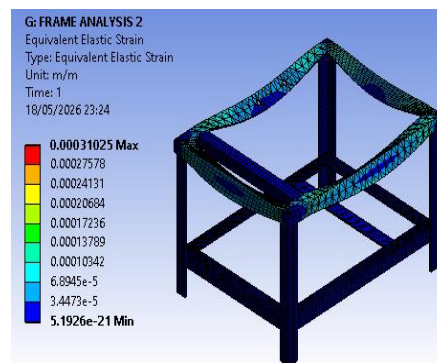


Fig 10: Equivalent strain

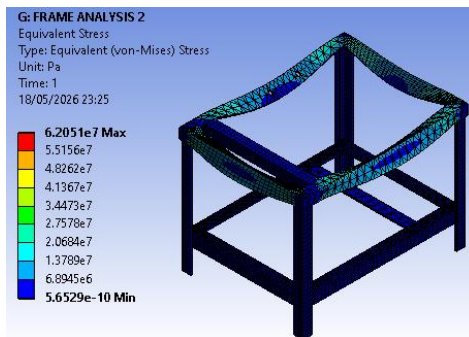


Fig 11: Equivalent stress

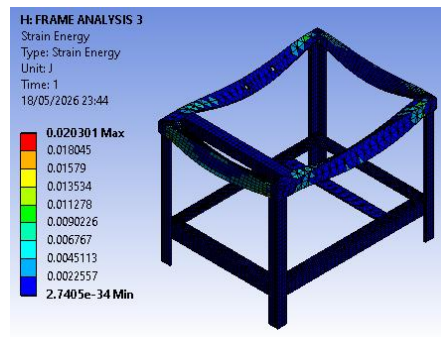


Fig 12: Strain energy

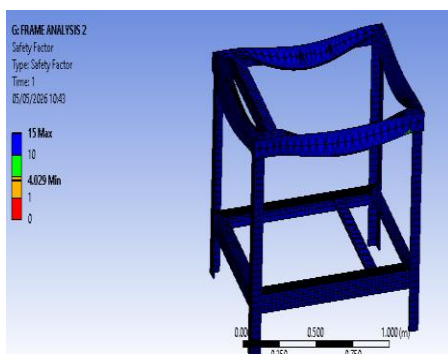


Fig 13: Safety factor

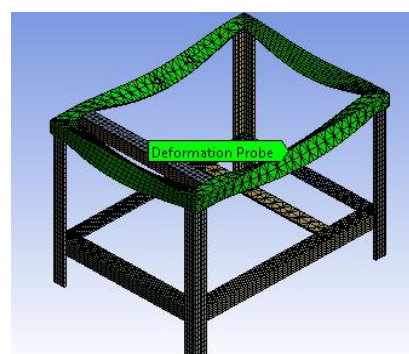


Fig 14: Deformation probe

5.2 Half Shafts-Crank Arm Assembly Analysis

- Analysis 1: applied force – 600N

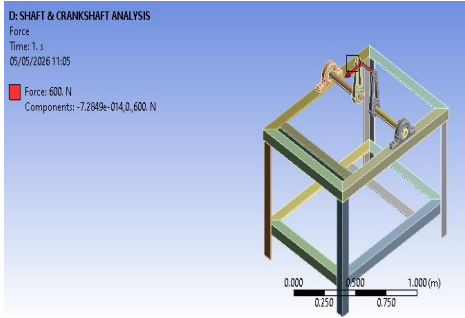


Fig 15: Direction of applied force

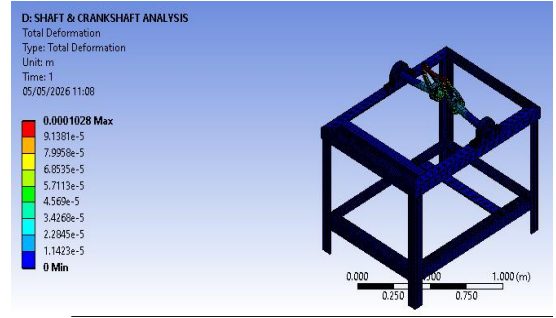


Fig 16: Total deformation

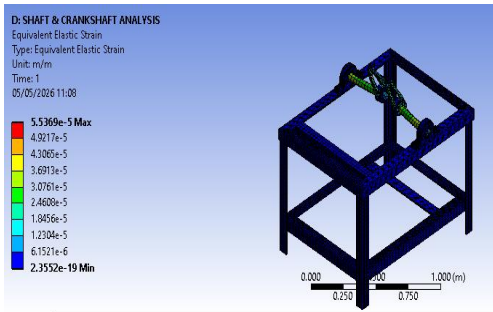


Fig 17: Equivalent strain

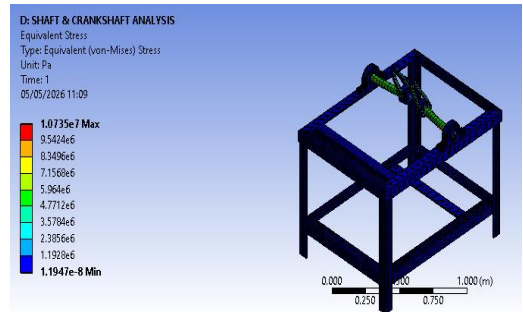


Fig 18: Equivalent stress

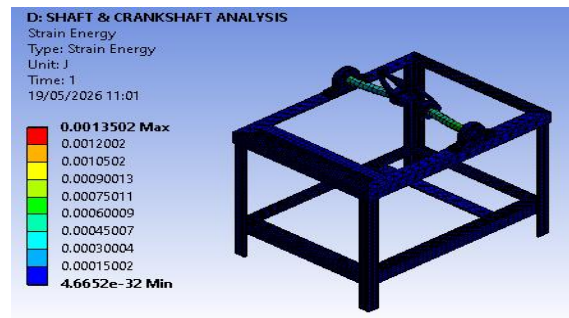


Fig 19: Strain energy

- Analysis 2: applied force – 5000N

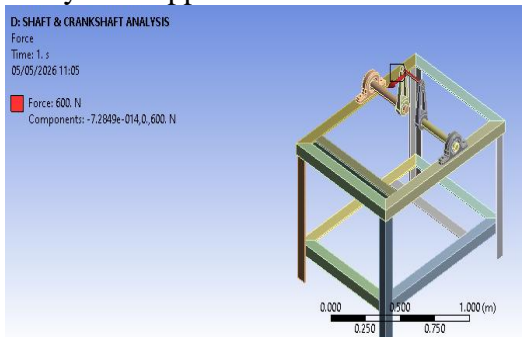


Fig 20: Direction of applied force

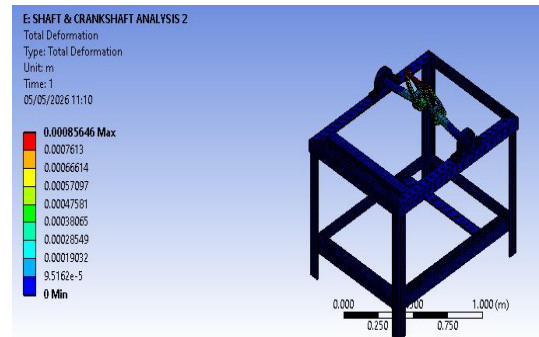


Fig 21: Total deformation

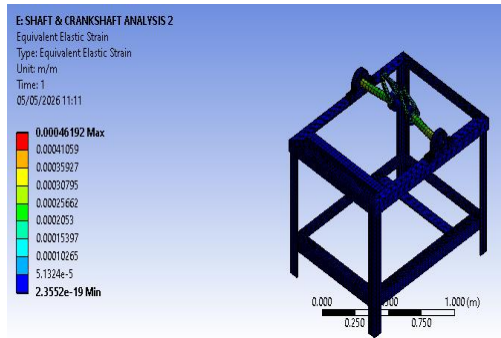


Fig 22: Equivalent strain

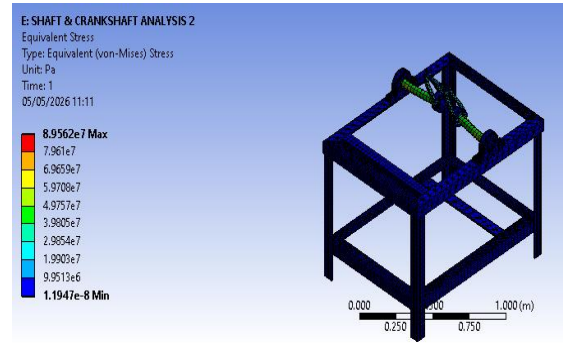


Fig 23: Equivalent stress

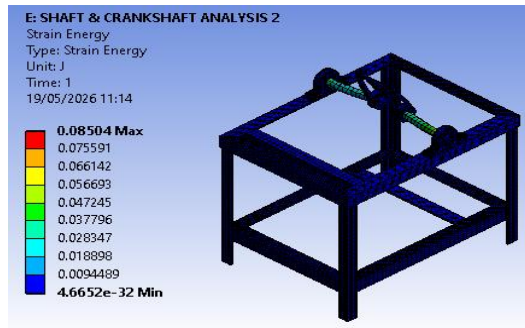


Fig 24: Strain energy

5.3 Piston-cylinder Assembly Analysis

- Applied force of 1000N

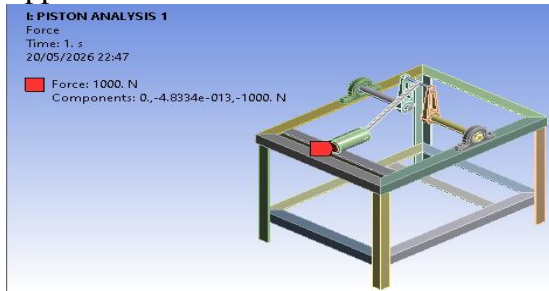


Fig 25: Direction of applied force

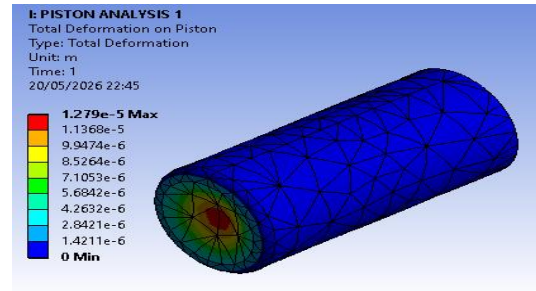


Fig 26: Total deformation

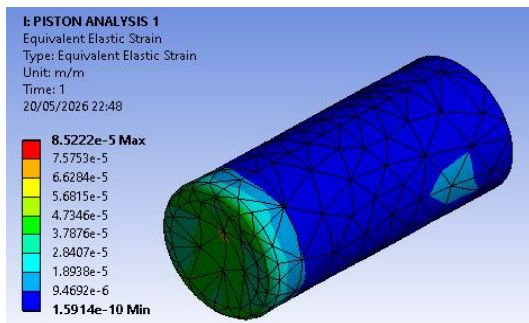


Fig 27: Equivalent strain

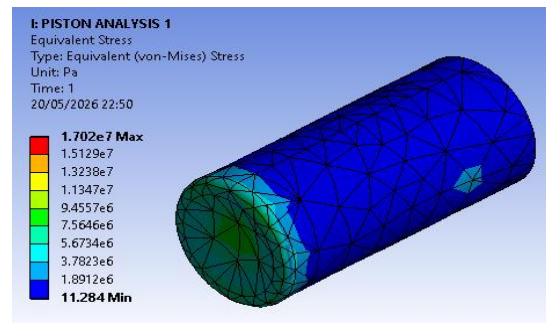


Fig 28: Equivalent stress

- Applied force of 5000N

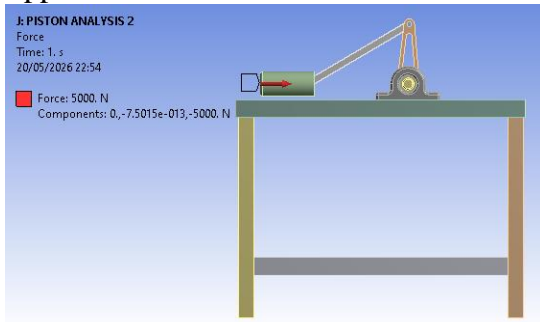


Fig 29: Direction of applied force

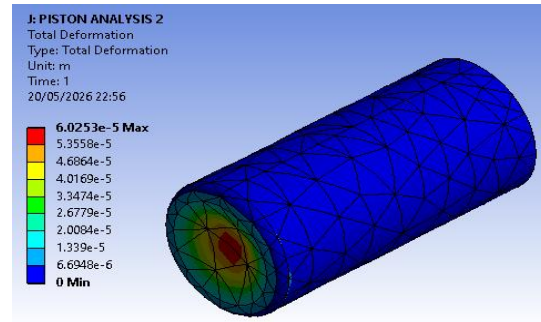


Fig 30: Total deformation

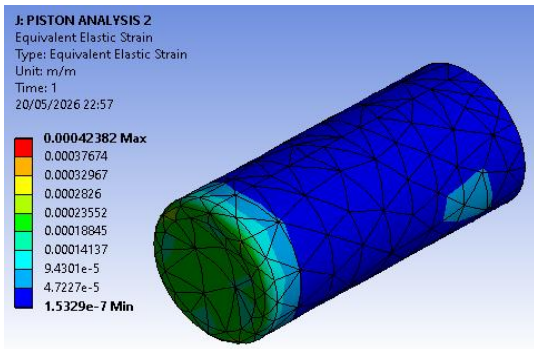


Fig 31: Equivalent strain

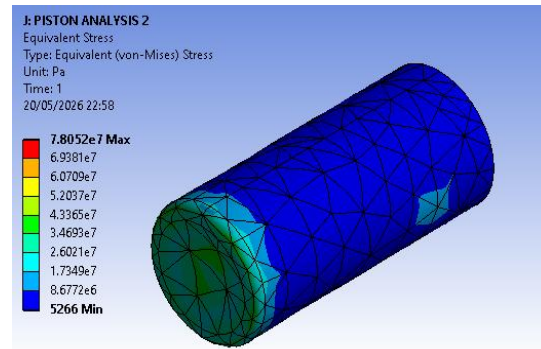


Fig 32: Equivalent stress

5.4 Assembly Analysis

- Applied force of 1000N at 800 rad/s (7640 rpm)

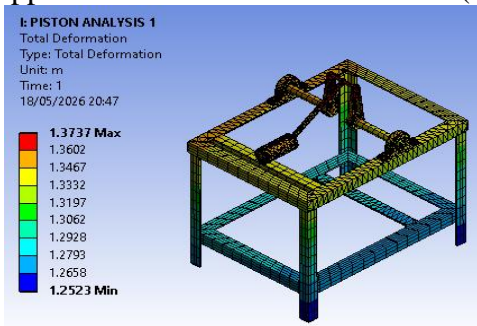


Fig 33: Total deformation

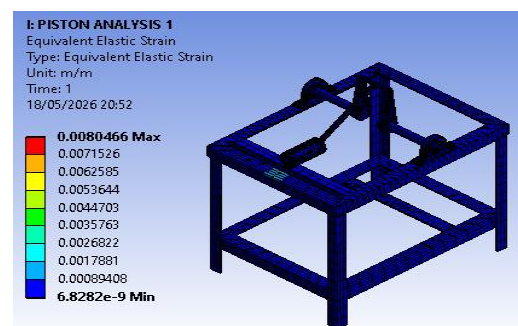


Fig 34: Equivalent strain

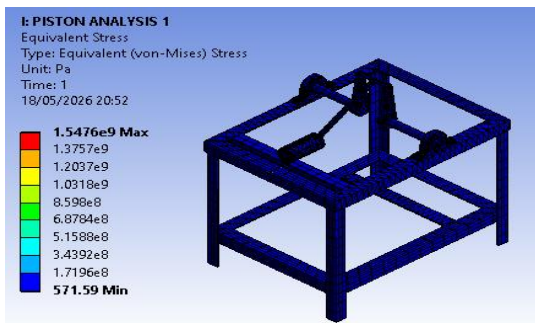


Fig 35: Equivalent stress

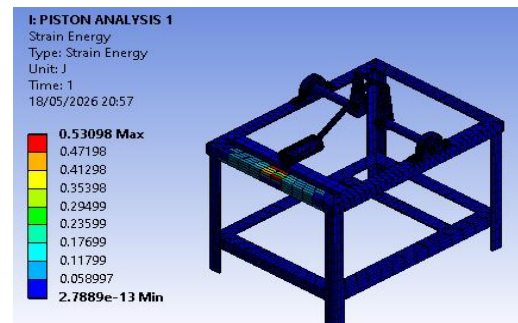


Fig 36: Strain energy

5.4 Total Deformation, Strain, Stress, Safety factor and Strain energy

- Frame: In Fig 4, a force of 1580N was applied on the upper four members of the frame, which results maximum deformation of 0.000142MPa and minimum deformation of 0.00MPa at point where the bearing carrying the half shafts will be fixed. Fig 5 and Fig 6 show that the maximum and minimum von-Mises strain and stress at these points are approximately 9.79×10^{-5} MPa and 0.00MPa, and 1.958×10^7 MPa and 0.00MPa respectively.

In Fig 7, the maximum and minimum strain energy are 0.000451MPa and 0.00MPa. While in Fig 8 the maximum and minimum safety factor at the two points are 15 and 12.346MPa, respectively.

Frame: In Fig 9, force of 5000N was applied at the same points of the four members of the frame, which results maximum deformation of 0.000395MPa and minimum deformation of 0.00MPa at point where the bearing carrying the half shafts will be fixed. Fig 10 and Fig 11 show that the maximum and minimum von- Mises strain and stress at these points are approximately 0.000305MPa and 0.00MPa, and 6.210×10^7 MPa and 0.00MPa respectively. In Fig 12, the maximum and minimum strain energy are 0.02031MPa and 0.00MPa. While in Fig 13 the maximum and minimum safety factor at the two points are 15 and 4.825MPa, respectively. Fig 14 shows a strong deformation probe area.

- Half shafts- crank arm assembly: In Fig 16, force of 600N was applied at the crank, which results maximum deformation of 0.000103MPa and minimum deformation of 0.00MPa at piston pin. Fig 17 and Fig 18 show that the maximum and minimum von-Mises strain and stress at these points are approximately 5.537×10^{-5} MPa and 0.00MPa, and 1.074×10^7 MPa and 0.00MPa respectively. In Fig 19, the maximum and

minimum strain energy are 0.00135MPa and 0.00MPa.

Half shafts- crank arm assembly: In Fig 21, force of 5000N was applied at the crank, which results maximum deformation of 0.000856MPa and minimum deformation of 0.00MPa at the point where the bearing carrying the half shafts is fixed. Fig 22 and Fig 23 show that the maximum and minimum von- Mises strain and stress at these points are approximately 0.000462MPa and 0.00MPa, and 8.956×10^7 MPa and 0.00MPa respectively. In Fig 24, the maximum and minimum strain energy are 0.0850MPa and 0.00MPa .

- Piston-cylinder assembly: In Fig 26, an impact force of 1000N was applied on the piston crown, which results to maximum total deformation of 1.279×10^{-5} MPa and minimum deformation of 0.00MP. Fig 27 and Fig 28 show that the maximum and minimum von- Mises strain and stress on piston crown of approximately 8.522×10^{-5} MPa and 0.00MPa, and 1.702×10^7 MPa and 11.264MPa respectively.

Piston-cylinder assembly: In Fig 30, an impact force of 5000N was applied on the piston crown, which results to maximum total deformation of 6.025×10^{-5} MPa and minimum deformation of 0.00MP. Fig 31 and Fig 32 show that the maximum and minimum von- Mises strain and stress on piston crown of approximately 0.000377MPa and 0.00MPa, and 7.805×10^7 MPa and 5266MPa respectively.

- Assembled machine: In Fig 34, by applying a force of 1000N at 7640rpm, results show maximum deformation of 1.374MPa and minimum deformation of 1.252MPa at crank pin. Fig 35 and Fig 35 show that the maximum and minimum von- Mises strain and stress at this point are approximately 0.008MPa and 0.00MPa, and 1.548×10^9 MPa and 571.59MPa respectively. While for the assembly, Fig 36, the maximum and

minimum strain energy are 0.531MPa and 0.00MPa,

- For the analyses performed on frame structure, half shaft-crank arm assembly, piston-cylinder assembly and machine assembly total deformation, equivalent strain, equivalent stress were observed to increase with load, while energy strain was observed to decrease with load.

6 CONCLUSION

The following conclusions are drawn from the FEA and simulation of the Can crushing machine:

- Geometry was modeled in SolidWorks and imported to ANSYS 16.2 workbench.
- The frame structure, shaft-crank arm assembly and assembled machine structure were each separately simulated and evaluated.
- Comparative analysis was performed by varying load and rpm

For the analyses performed on frame structure, half shaft-crank arm assembly, piston-cylinder assembly and machine assembly total deformation, equivalent strain, equivalent stress were observed to increase with load, while energy strain was observed to decrease with load.

7 RECOMMENDATION

It is here recommended that for future modifications the materials used for this fabrication of the piston-cylinder arrangement be put under consideration as good material selection will help reduce friction, eventually, wear of these parts. Also, attention should be given to how to reduce vibration of the frame when the electric motor is working.

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