DESIGN OF A PEDAL POWERED MACHINE TO ENHANCE SHEAR NUT PROCESSING

ASHESI UNIVERSITY

CAPSTONE PROJECT

B.Sc. Mechanical Engineering

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Mechanical Engineering.

Benjamin Aboagye

2021

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate’s Signature:

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Candidate’s Name:

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Date:

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I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University College.

Supervisor’s Signature:

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Supervisor’s Name:

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Date:

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Acknowledgements

To begin with, I would like to thank God for his guidance throughout this project. The project would not have been possible without His grace and mercies.

Special thanks go to my supervisor, Dr. Danyuo Yiporo for his incredible patience, time and feedback during the project.

Finally, I would like to thank my colleagues who shared their ideas on the implementation of this project.

Abstract

Shea nut is a very important commodity across many parts of the African Continent. The Shea tree has numerous socio-cultural and economic benefits to people living in its geographic area and to the nation at large. Despite the fact that the shea nut industry has contributed significantly to the economic growth of the nation, the method (manual/traditional) by which shea products are processed is tedious and time-consuming which need to be addressed. The current work focused on designing a pedal powered machine that would enhance shea nut roasting. Conceptualization was achieved with free hand sketches and 3d models using SolidWorks. Methodology involves numerical calculation, static analysis, fatigue analysis, vibrational simulation, in SolidWorks. The results showed that the stress on the shaft lies at the edges of the fins, and the factor of safety obtained after design lied between 1.9 to 5.5. Also, the result showed the minimum natural frequency of the cylinder to be ranging from 2947.5 Rad/sec and the maximum being 13449 rad/sec.

The result implies that the shaft design was safe as far as the factor of safety is concerned and excessive vibrations beyond the minimum frequencies might lead to structural and functional issues.

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CHAPTER ONE

1.0 Introduction

1.1 Background

Shea nut is one of the most important oil-bearing materials. It is considered as one of the substantial crops in Africa, especially in West Africa [1]**.** Shea nuts are obtained from the Shea tree known as *Vitellaria paradoxa.* Shea trees are naturally found in 19 countries across the African Continent including Ghana, Cameroon, Central Africa Republic, Sierra Leone, etc. [2]**.** In Ghana, shea trees are mostly found within the entire Northern Sectors (Savannah Region, Upper West Region, Upper East Region, and Northern Region) with sparces of them in Brong Ahafo, and Volta Region [3]**.** It grows mainly in the wild state and does very well on a wide range of soils, including arid, semi-arid, and rocky soil [4]**.** Shea tree grows at about a height of 25 m. It takes about 10-15 years for the fruiting to begin, and it takes about 30 years to reach maturity[5]. The shear fruits comprise two components: pulp and kernel or the nut. The nuts are brown and have an oil content of about 50% [6]. The oil or the shea butter is very important, and its essence is seen by both West Africa, Africa, and outside of Africa. It is used as a raw product to manufacture products such as soaps, candles, and cosmetics. It is also used in pharmaceutical applications and food processing. The importance of shea nut cannot be over-emphasized; however, it is a significant source of income to the Ghanaian economy. The oil from the shea nut is obtained through processes, namely: shelling, crushing, roasting, milling, and kneading [7]**.** In most parts of Africa, the shelling, cracking, roasting, and oil extraction are done manually in a tedious manner and time-consuming. These strenuous traditional methods of extracting the oil can result in low productivity and reduced quality of shea butter.

1.2 Problem Definition

In most rural communities in Ghana, where shea nuts are majorly harvested, the extraction of the butter is currently being achieved using traditional methods. Shelling of the nuts for example, involves the use of sticks, stones, mortar, and pestles which are arduous tasks and time-consuming [8]. These tools are currently used due to the unavailability of alternative machines to perform this tedious task. Some women have been supported by a non-governmental organization (NGO) with machines, but the numbers overweigh the available resource, and cost for the current equipment are expensive to be accessed by the local people due to low incomes. An example of such an NGO is the Burn Design Lab, a Seattle based NGO who designed the smokeless roaster to expose women to less smoke and heat [9]**.** Even when the equipment is available, it is either positioned at a point within communities to serve the majority or at a distance which creates problems with transportation. This can significantly increase the cost of the shea butter produced.

Given the fact that this is a cash crop and of immense benefits to the economy, there is the need to increase the productivity of the shea butter. Therefore, the need for a machine to improve on the quality of nuts shelled as well as increase productivity, part of which this work seeks to address.

1.3 Motivation for the Project

The observed practical difficulties faced by shea nut processing have been a source of motivation toward designing alternative equipment to enhance the development of women in the area. From the activities involved in the process, it was realised that most are health-threatening (done manually), and these could be harmful to their health, especially when they come into contact with open fires during roasting. In fact, all crops of human sustenance are produced and processed by the human muscles, but farming has evolved sufficiently for farmers to demand mechanization [10]. The access to agricultural machinery could help overcome labour constraints hence intensify the production of cash crops. This could also increase efficiency. The availability of a machine that could perform these health-threatening tasks would help alleviate this problem. This work seeks to design a pedal-powered machine to enhance shea nut processing (roasting and oil extraction).

1.4 Goal and Objectives

The main goal of this project is to design a pedal-powered machine for the roasting and shea butter extraction. From the problem statement, associated challenges were identified on shea nut butter processing, especially crushing, and roasting. In other to increase productivity, this project would be accomplished via the following specific objectives:

- Conducting detailed material selection using Cambridge Engineering Selector (CES): Mechanical properties versus cost, Mechanical properties versus lightweight materials, and Mechanical properties versus thermal properties.
- Three-dimensional design of parts and parts assembly: conceptual designs.
- Numerical and mechanical design of shaft for pedal-powered machine for shea nut roasting and oil extraction
- Numerical and computational modelling with a focus on design parts, mechanical-statics analysis, fatigue analysis, and thermal analysis
- Construction and testing of the system: determine the torque required and power transmitted to drive the crusher (assisted with a spring balance).
- Demonstration and testing of the system on enhancing oil recovery with the design machine.

1.5 Requirements

The shea nut processing machine to be designed needs to have the following requirements:

1. The design should be user-friendly (ergonomics). It should be maintainable.

2. The design should be guided by materials selection to reduce cost and enhance mechanical durability.
3. The product should require less power to operate/incorporate manual operations but less stressful.

1.6 Proposed Solution

The proposed design for the problem is a pedal powered machine. It will utilize pedal power for its application. This refers to the arrangement of mechanical parts that convert linear motion to rotational motion.

CHAPTER TWO

2.0 Literature Review

2.1 Brief Statistics

Shea tree grows naturally in the wild and in the dry Savannah belt of West Africa from Senegal to Sudan in the east and onto Ethiopia highlands [11]**.** The species are of African Origin (International Plant Genetic Resources Institute, 2006) and is found in areas with 400-1800 mm rainfall per year [11]. It occurs in 19 countries across the African continent, including countries like Cameroon, Ghana, Central African Republic, Guinea Bissau, Mali, Nigeria, Niger, Togo, and Uganda [12]. In Ghana, the shea tree grows extensively in the Guinea Savannah and less in the Sudan Savannah [12]. It covers almost the whole area of Northern Ghana, over about 77,670 square kilometers in Western Dagomba, Southern Mamprusi, Western Gonja, Lawra, Tumu, and Wa. According to [13]**,** Africa produces approximately 1,760,000 tonnes of raw shea nuts annually. In Ghana, about 9.4 million shea nut trees were projected to produce at least 60,000 metric tonnes of shea nuts per annum for the production of all shea butter processed locally. Nigeria was the largest producer of shea nuts in 2017, according to the Centre for the Promotion of Imports (CBI). CBI is an organization that contributes to inclusive and sustainable economic development in developing countries [14]. Figure 2.1 shows the production of shea nut in tonnes by African countries as of 2017.

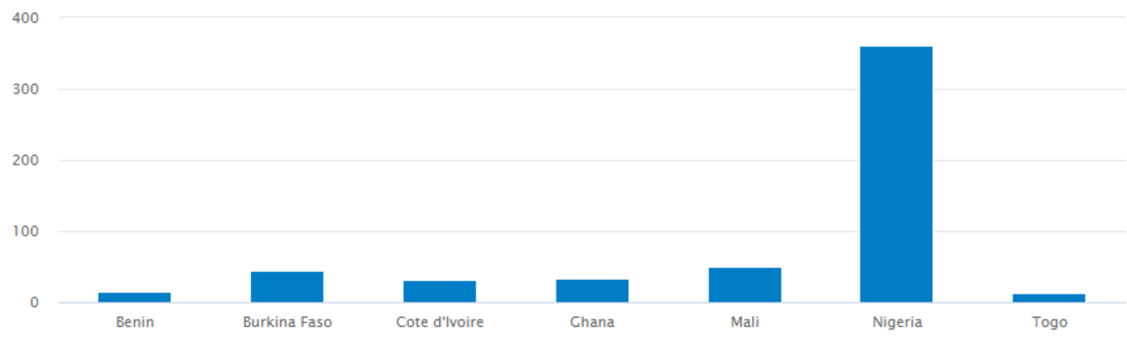


Figure 2.1: Production of Shea nut in Africa 2017 (CBI)

The shea nut market in Ghana is well established, being sold both locally and internationally. Ghana in 1996, exported about 21,467 tons of shea nut worth $4,484,600 [14]. In 2018, the export of shea nut from Ghana reached 27 967 tonnes, and it is currently valued at 66 million dollars [16]. According to the CBI, Mali is known to be the largest exporter of shea nut with 75,000 shea nut-Equivalent tonnes (SET) followed by Burkina Faso and Ghana with 70,000 SET and 60,000 SET, respectively. Europe accounts for about a 35% share of the global market of shea butter. It is estimated that about 250,000 tonnes of shea products are exported annually to Europe [14]. According to [14], the 'non-traditional' market for shea butter has used it as a source of vegetable fat, mainly in the formulation of Cocoa Butter Equivalent (CBE). Shea butter export has been increasing in recent years since becoming a substitute for cocoa butter extract in the cosmetic industry. It is estimated that shea can potentially yield up to 150 million US Dollars and contribute up to 12% of the total household income in the poorest households of the savannah areas [15]**.**

Figure 2.2 shows the biggest importers in Europe of shea butter for vegetable fats and oil in 2018. France is the leading importer of shea butter, and this is due to the fact the country has a strong cosmetics manufacturing sector.

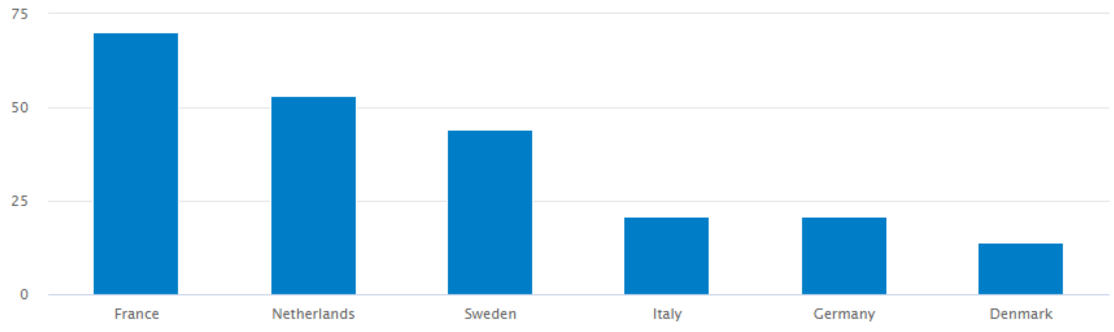


Figure 2.2: Import of Shea nut by European Countries (CBI)

2.2 Applications and Uses of Shea Butter

Shea tree has both economic and social or socio-cultural values with applications in industries such as food, pharmaceutical, and cosmetics. Shea oil is a common ingredient in cooking, and it is the primary cooking oil in parts of West Africa, including Ghana. The oil is used as a raw material for cooking, cosmetics, soap, and candles. About 90 percent of the traded shea butter are processed for the inclusion of food such as chocolate and margarine [14]. The immense medicinal value of shea butter cannot be overemphasized. The presence of allantoin in the shea butter gives it anti-inflammatory properties, and therefore it can provide relief for dry skin prone to diseases such as neurodermatitis. Unrefined shea butter is useful in the treatment of skin rashes, stretch marks, burns, athlete foot, insect bites, arthritis, and muscle fatigue [16]**.** Shea butter also has some effects on cholesterol metabolism [16] observed and reported that the usage of shea butter led to a reduction in low-density lipoprotein and total cholesterol. Israel [17] discovered that the administering of shea butter leads to a decline in the protein concentrations of the hepatic and renal tissues and also in the serum. The decline has been attributed to the presence of a chemical substance known as Saponin. Saponin causes a reduction in the digestibility of protein by forming a digestible saponin-protein complex in the intestine.

Shea butter has a very exceptional healing fraction. It contains essential nutrients, vitamins, and other essential phytonutrients required for healing. The healing fraction of shea butter is very high, and the higher the healing fraction, the better the chances are for a good quality shea butter [17]

Shea butter is significantly used in the cosmetic industry, both locally and internationally. For most industrial processors, Shea butter is a low-cost substitute product sold into the cocoa butter equivalent markets, and the shea produced in West Africa supplies this market. In the cosmetic industry, shea butter is used to manufacture body lotions for treating skin cracks, tough or rough skins. It acts as a skin moisturizer due to its sun screening properties [18].

2.3 Highlights of Techniques used in Shea Processing.

This section would consider various techniques involved in the processing of shea butter which would later be explained in depth in the methodology section. The process begins with fruiting and the gathering of the shea nut, which usually occurs between the months of May to August every year. The figure below is a simple flow chart that highlights the stages in the processing of the shea nut into butter.

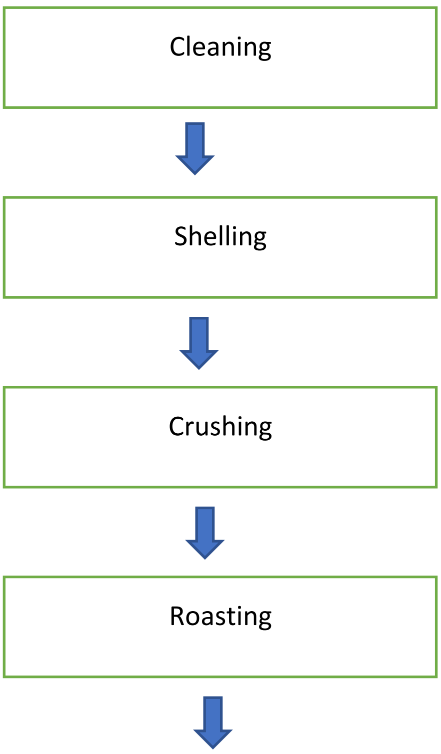


Figure 2.3: Flow chart of shea butter making process.

Each stage in the process is done manually or traditionally. This could be time-consuming, physically exhausting, and labor-intensive due to the unavailability or the inaccessibility of a machine to lessen the intensive nature of labour associated with the shea butter production. Apart from the fact that it is a labor-intensive process, it can not be doubted that there is a huge market for the shea butter business.

2.4 Existing Interventions for Roasting Shea Nut

With regards to roasters, some efforts have been made by researchers. Balami et al. [19] designed a roasting machine made of aluminium plates of about a millimeter in size. The roasting machine composed of a hopper, boiling unit, roasting chamber, and a discharge unit. The crushed kernel flows into the cylindrical-shaped hopper into the roasting chamber. The source of heat for roasting is a charcoal-fuelled burner which is fixed at the bottom of the tank. The roasting chamber has stirring blades attached to a shaft driven by a motor.

Figure 2.4: Shea nut kernel roaster [19].

Another kind of shea nut roasting machine was designed by Tulashie et al., [20] which consisted of a seed inlet, insulator, rotary handle, and a basement. The roasting chamber helps in the turning or stirring of the nuts. The heat source necessary for the roasting is found in the basement chamber situated beneath the roaster. The heat from the burnt firewood in the chamber is transferred through convection to the outer walls of the roasting chamber hence enabling roasting to take place by heat conduction. The insulating chamber helps in the reduction of heat loss by conduction through the walls of the roaster.

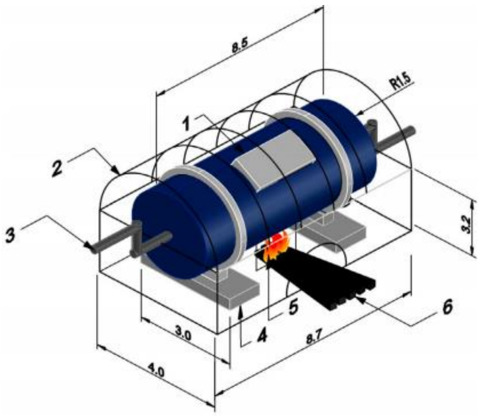


Figure 2.5: Design of a shea nut rotary roaster machine.

2.5 Unresolved Issues(challenges)

The existing technologies have shown remarkable improvement in handling shea nut processing. However, they are not without challenges for improvement. The current machines use electric motors. In the case of rural communities without the national grid or some form of power generation, such equipment cannot operate in selected locations. Because shea harvesting is done in the rural areas of the country, it would help resolve these challenges by harnessing pedal energy to power the operations. The machines considered above appeared heavy and bulky, which makes them quite challenging to transport. This project would make use of materials selection to enhance performance and durability. Regarding the shaft and its design, in Tulashie et al. [20] design of the roasting chamber, the shaft was attached to a gear motor. This motor rotates the shaft, which has blades attached to them. Unlike Tulashi and Balami, this project will not make use of a motor but instead a bicycle which will harness pedal power to drive the shaft. The rotational motion would be transmitted to the shaft by the pedal through the chain connected to the sprocket. The shaft design will consist of a cylindrical design with some flat vertical structures attached to it. This is to help scoop or stir the shea butter when it's being roasted, so in that sense, it mimics the scooping action. Since the rotating shaft has a torque component, the torque transmitted by the shaft is determined from the formula:

$$T = \tau \text{ x } \frac{J}{r} \tag{2.1}$$

where J is the moment of inertia, r is the radius, and τ refers to the shea stress imposed on the shaft. The shaft will be subjected to torsional shear stress with no bending stress component. According to Budynas et al., [20], the power delivered by a shaft is given by

$$P = F \times V \tag{2.2}$$

where P = power (Nm/s), F = force of threshing, and V = velocity.

2.6 Scope of Work

This project covers the material selection, design, and fabrication of a pedal-powered machine. The work will also involve fatigue analysis of the components for an effective design.

Chapter one covers the introduction, where the background study is discussed as well as the problem definition and the motivation for the project. The goals and objectives of the project are outlined in the chapter and also the proposed solution for the problems stated.

In chapter two, a brief statistic about shea nut (market size, export, import) was presented and discussed. The other topics in this chapter include the application of shea butter, techniques in the processing of shea butter, existing interventions, and unresolved challenges that this project seeks to address.

Chapter three covers the methodology of the project and design criteria. The procedure of the shea butter processing is explained in-depth, and the material selection for the various components of the design are also discussed. The design is shown where the CAD design and the machine is demonstrated. Analysis and calculations are done based on relevant theories as well as the calculations.

In chapter four, the implementation of the design is shown. Results of simulations and analysis such as static analysis, fatigue analysis, thermal analysis, and other forms of analysis are discussed in this section.

Chapter five covers the conclusion and recommendations for future works.

CHAPTER THREE

3.0 Materials and Methods

This section of the paper details the design of the machine and the mathematical analysis of the various components. A design criterion was used for the various conceptual designs of the proposed machine. The material selection for the various components is analysed based on criteria such as Young's modulus, Stiffness, and Strength. Also, this section describes the fabrication techniques used in the process of the fabrication.

3.1 Numerical Calculation

Calculations were done on various components of the system to examine and determine the dimensions for the system to be modelled in SolidWorks.

3.1.1 Analysis of Pedaling Rate

Pedal power is the energy required from the pedaling action. This power is transmitted to the shaft through the chain drive. Human beings can produce power over a wide range of speed. The rate of speed may vary from person to person owing to reasons such as physical conditions and others like body configuration and orientation. According to Kassim et al. [21], the average or moderate speed a person can cycle is 6.67 m/s, with the mean speed for all ages being 4.166 m/s.

3.1.2 Analysis of Chain and Sprocket.

The chain drive is a way of transmitting the mechanical power from one component to the other by means of sprockets and chains. This project makes use of driver (bigger) sprocket which has 64 teeth and diameter of 32 cm, with smaller sprocket, which has 32 teeth and diameter of 16, cm respectively. The bigger sprocket drives, the smaller one, which is coupled with the shelling shaft. Assuming the speed of the user is considered to be 6.67 m/s as posited by Ali et al. [21], the speed of the driven sprocket can be calculated using the formula.

$$\frac{T_1}{T_2} = \frac{V_1}{V_2} \tag{3.1}$$

where T_1 is the number of teeth of the driver sprocket, T_2 is the number of teeth of the driven gear, V_1 is the speed of the driver sprocket, and V_2 is the speed of the driven sprocket.

The speed of the driven sprocket is then calculated.

$$V_2 = \frac{T_1}{T_2} \text{ x } V_1 = \frac{50}{25} \text{ x } 6.67 \tag{3.2}$$

$$V_2 = 13.34 \text{ m/s}$$

o r $$V_2 = 909.46 \text{ rpm}$$

(a) (b)

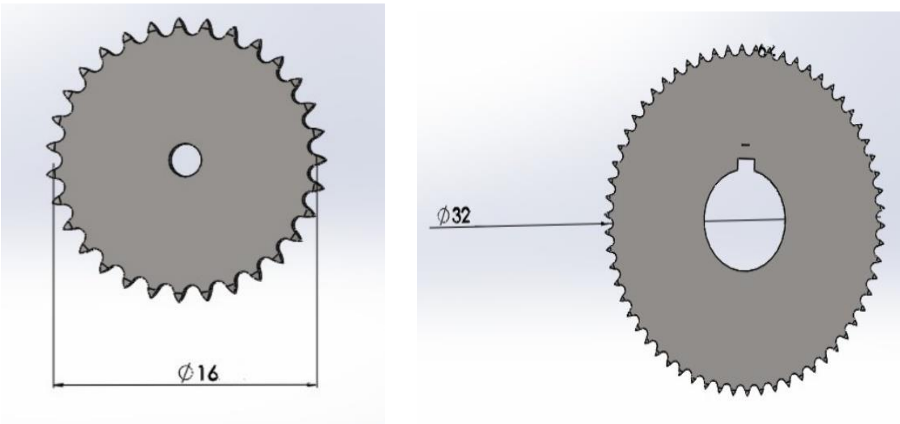


Figure 3.1: (a)Smaller sprocket and (b)Bigger Sprocket

3.1.3 Seat Post Analysis

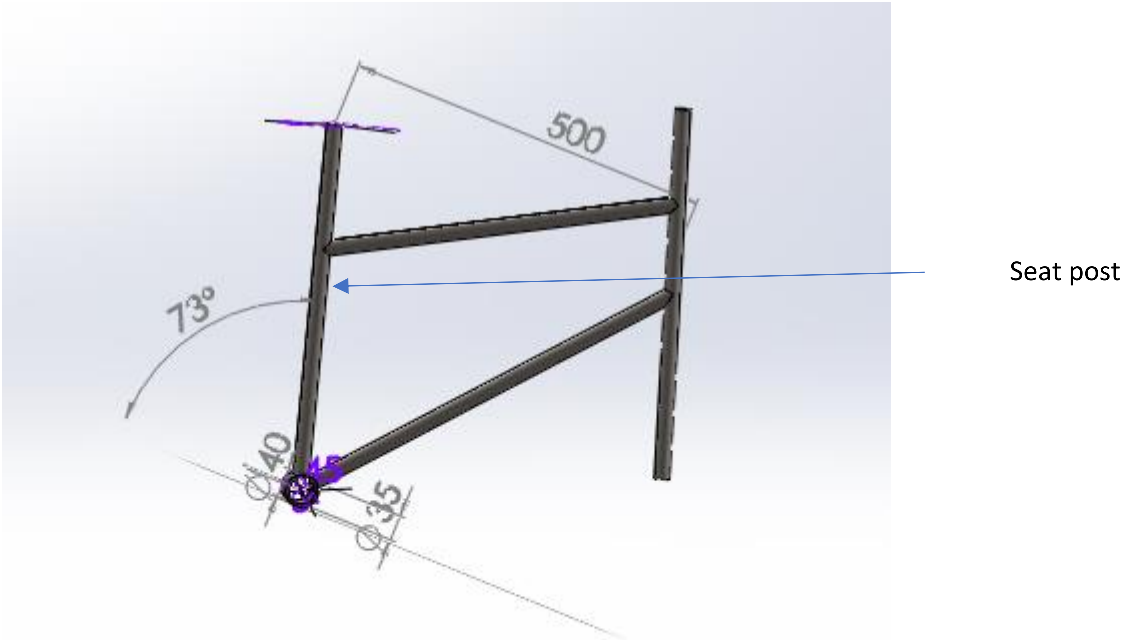


Figure 3.2: Seat post

The seat post refers to the tube which extends from the bicycle frame to the saddle. It is the bar that supports and positions the saddle on top of it. There is a significant amount of

force that the ground transmitted up through the frame and seat post into the user alongside with a downward compression from the weight and gravity of the user.

Assuming the weight of the user is 600 N, the compressive stress exerted on the column by the user can be calculated as follows [22]:

$$\sigma = \frac{P}{A} \quad (3.3)$$

where $A = (\pi r_{outer}^2) - (\pi r_{inner}^2)$, inner radius of 0.015, outer in radius = 0.016 m.

$$A = (\pi(0.016\,)_{outer}^2) - \pi(0.015)_{inner}^2$$

$$= 0.002061m^2$$

Therefore, the stress was calculated as

$$\sigma = \frac{600}{0.00206} = 29.126\ kN/m^2$$

The applied compressive stress is found to be $29.126\ kN/m^2$. The allowable stress of the column is given by the formula:

$$\text{Allowable stress, } \sigma_{steel} = \frac{Yield\ stress}{Factor\ of\ safety} \tag{3.4}$$

$$= \frac{280000}{4}$$

$$= 43\ KN/m^2$$

Since the applied stress is less than the allowable stress the column is not going to fail by compression. Another possible mode of failure is buckling. Buckling is a failure mechanism that occurs in columns due to compression and characterized by a change in the shape of the column. The column fails by buckling when the critical buckling load is reached. The critical buckling load can be found using the Euler column formula [23]

$$P_{cr} = \frac{\pi^2 EI}{L^2} \tag{3.5}$$

where, E = modulus of elasticity of the material, and I= moment of inertia:

$$I = \frac{1}{2} M(R_2^2 + R_1^2) \tag{3.6}$$

$$P_{cr} = \frac{\pi^2 * 6.9 * 10^{10} * 0.000125}{0.075^2}$$

$$= 15133\ MN/m^2$$

3.1.4 Analysis of Shaft

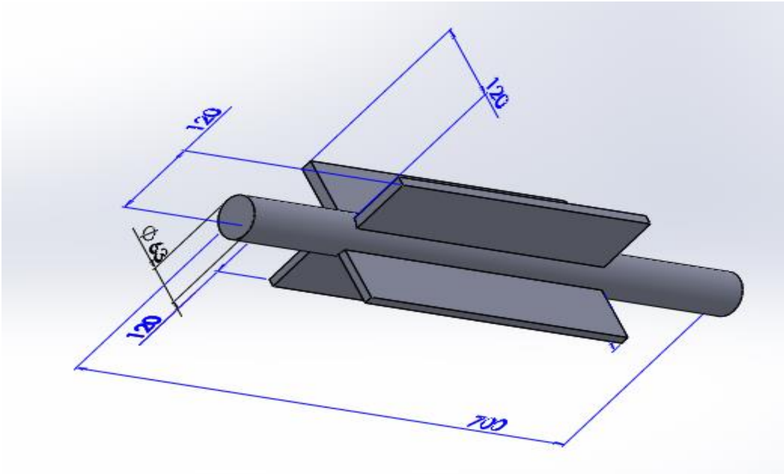


Figure 3.3: Solid Shaft

The shaft in the roasting cylinder is responsible for the mixing and turning of the shea nut as it is being roasted. The understanding of the shaft design is needed to prevent failure of the shaft during the operation of the machine. The rotation of the solid shaft is as a result of the torque acting on it. Given the diameter (d) of the shaft to be 63mm and taking maximum allowable shear stress to be 60MPa. The torque of the shaft is obtained from the following calculation [22]:

$$\frac{T}{J} = \frac{\tau}{r} \tag{3.7}$$

where, T is the torque, J is the polar moment of inertia, τ is shear stress and r is the radius.

For a solid circular shaft, $J = \frac{\pi}{32} d^4$, therefore:

$$T = \tau \, x \, \frac{\pi}{32} \, x \, d^4 x \frac{2}{d} \tag{3.8}$$

$$T = \tau \, x \frac{\pi}{16} x \, d^3 \tag{3.9}$$

$$= 60 \, x \frac{\pi}{16} x \, 63^3$$

$$= \ 2.94 * 10^6 \text{ N} - \text{mm}$$

The torque on the shaft was found to be 2.94 x 10^6 N-mm.

To determine the minimum required diameter of the shaft, a factor safety of 2 is assumed and a yield strength of 580MPa.

$$n = \frac{\sigma_y}{\sigma_w} \tag{3.10}$$

$$\sigma_w = \frac{800}{2} = 400MPa \tag{3.11}$$

$$400 = \frac{4 * \ 10kN}{\pi * d^2}$$

$$d = 6.6260 \ mm$$

To estimate the fatigue of the shaft material the theoretical fatigue endurance limit can be calculated. Assuming the steel is a 1050 CD steel, the endurance limit at 10^6 cycles can be estimated as:

$$S_e' = 0.5(S_{ut}) \tag{3.12}$$

where S_{ut} is the ultimate tensile strength of the material given as 90 kpsi

hence, $$S_e' = 0.5(90) = 45kpsi$$

The endurance strength of the shaft corresponding to 10^4 failure can be estimated as:

$$S_f' = aN^b \tag{3.13}$$

where, $$a = \frac{(fS_{ut})^2}{S_e} \text{ and } b = -\frac{1}{3}\log\left(\frac{fS_{ut}}{S_e}\right) \tag{3.14}$$

Given S_{ut} to be 90, f can be determined from the fatigue strength curve as approximately 0.86.

Hence, $a = \frac{[0.86(90)]^2}{45} = 133.1 \ kpsi$ and $b = -\frac{1}{3} log \left[\frac{0.86(90)}{45}\right]$ = -0.0785

Therefore, for 10^4, $S_f' = 133.1(10^4)^{-0.00785}$ = 65 kpsi.

3.2 Conceptual Designs

Conceptual design ideas were considered at the beginning of the design phase using hand sketches. Considerations focused on identifying the technical and economic feasibility of the project. Thus, parameters include; ease of operation, portability, cost-effectiveness, and ergonomics. It also took into account the pros and cons of the ideas generated with respect to control parameters in the areas of its functionality, efficiency, cost, lightweight, and among others.

3.2.1 Design Concept 1

This design concept (Fig. 3.4) comprises of hopper with a cylinder positioned right beneath it. The cylinder is fixed to the hopper making it difficult to separate. A bicycle frame is connected to the sprocket my means of a chain drive. The driver sprocket on the bicycle frame is attached to a stand to support the seat post. The pedalling power is transferred by means of the chain connected to the shaft and the sprocket on the bicycle.

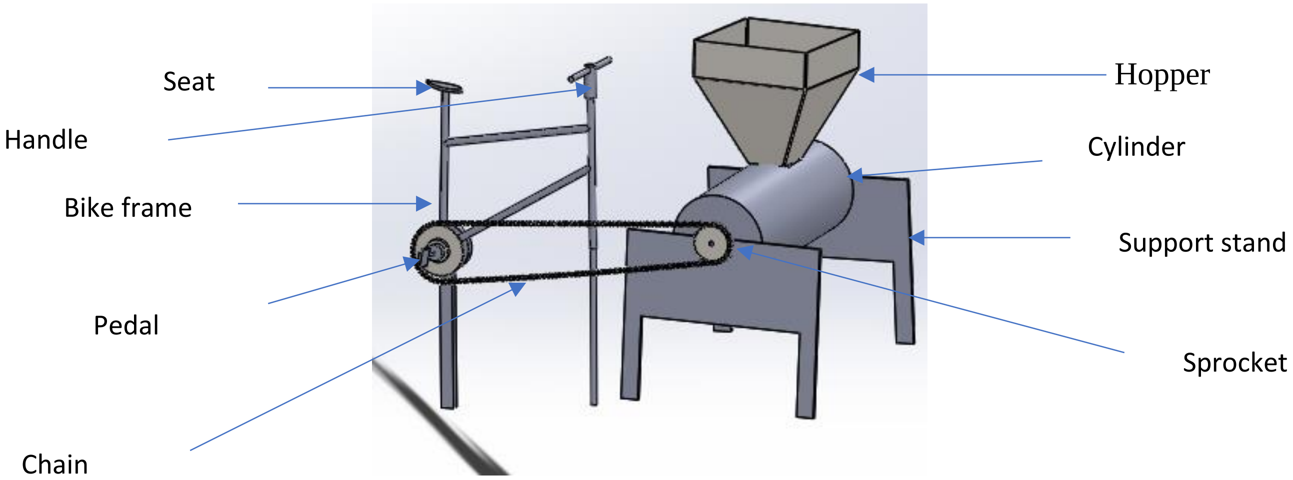
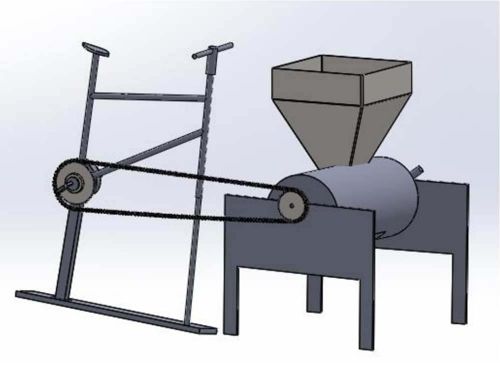


Figure 3.4: Design concept 1

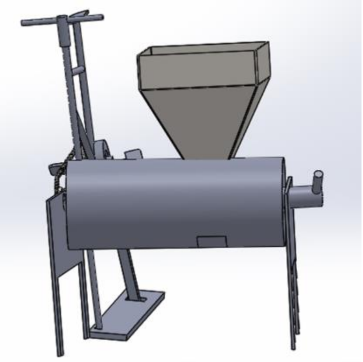
3.2.2 Design Concept 2

This concept (Fig. 3.5) is similar to the first but differ from it in the sense that the cylinder has an insulated handle which provide the option of propelling by hand. This serves as an added advantage to the pedalling. This could be particularly useful to users who cannot use their legs due to health reasons or other peculiar reasons. The bike is placed at a considerable distance from the roaster to avoid any health hazard due to smoke among others.

(a)



(b)



(c)

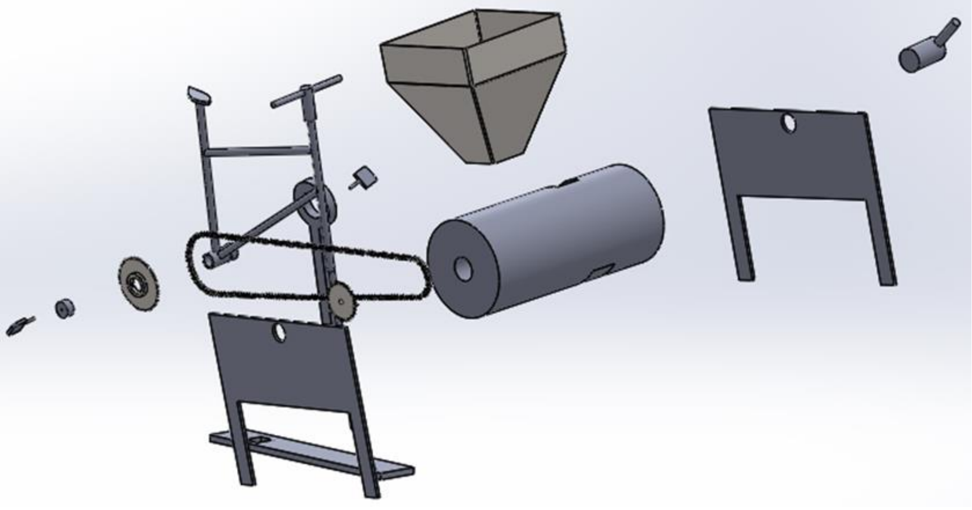


Figure 3.5: (a) Design of concept 2, (b) Front View of Design Concept 2, and (c) Exploded View of design concept.

3.2.3 Design concept 3

Design concept 3 (Fig. 3.6) does not include the bicycle frame and seat post. It has a pedal attached to a sprocket mounted on a stand. This design has a pedal and a hand crank that gives the user the option to turn the roaster by hand. The hand crank is insulated since it can be hot during roasting.

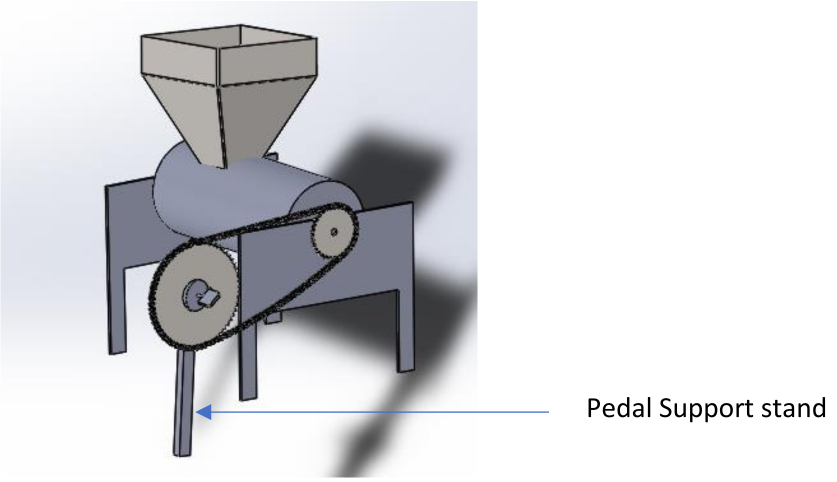


Figure 3.6: Design concept 3

3.3 Design Selection Matrix and Criteria

A design criterion is set, and a decision matrix was created to evaluate various aspects of the design ideas. Pugh matrix was used to assess the design criteria. The reference to the Pugh Matrix was the traditional form of roasting as a reference and evaluations were done based on the set criteria. Various concepts were compared based on the simplicity, size, durability and effectiveness (Table 3.1). The total score is the net value on a specific column. The Rank positions the various design concepts based on the net score. All the three design concepts are relatively easy to use. Design 3 is the easiest since it gives the user varied options as to how to comfortably go about the roasting of the shea nut.

The second concept design, apart from being simple to use, is also very effective and reliable. It also gives the user varied options, such as the use of the hand crank instead of the pedal. Both the second and third design concepts are useful to the user in terms of the fact that the user can use it as an exercise for health benefits. The concept design three occupies [less space] unlike the two other designs. The second concept design appeared to satisfy the criteria and was chosen for the machine.

Table 3.1: Pugh Matrix for design concepts

Criteria	Baseline	Concept 1	Concept 2	Concept 3
Simplicity	0	+1	+1	+2
Effectiveness	0	+1	+2	+1
Size	0	+1	+1	+1
Durability	0	+1	+1	+1
Reliability		+1	+2	+1
Total	0	5	7	6
Rank		3	1	2

3.4 Functional Block Diagram of the Design.

The following block diagram (Fig. 3.7) describes the operation of the pedal powered shea roasting machine.

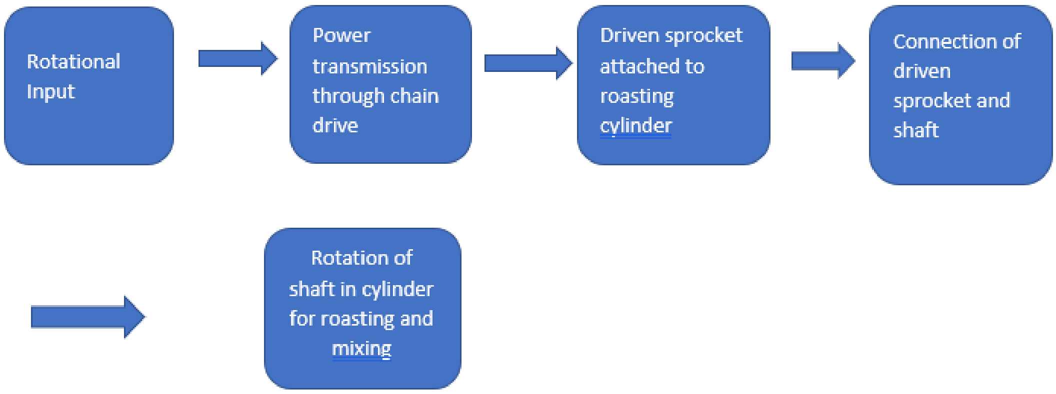


Figure 3.7: Flow chart of operation of machine.

3.5 Material Selection

Material selection is the foundation and a vital component of a design project. The selection process of material for the component involves consideration towards the application requirements, the likely materials, and the physical principles. Materials are selected on the basis of the functional requirements and material properties or constraints. Also, objectives such as the cost and minimum weight also informed our decision the material to be used. The pedal machine is broken down into various components to make it easier for the material selection process of each of component. The main components of the system are:

a. Hopper
b. Cylinder
c. Rotating Shaft
d. Chain Drive and Sprocket
e. Bicycle frame

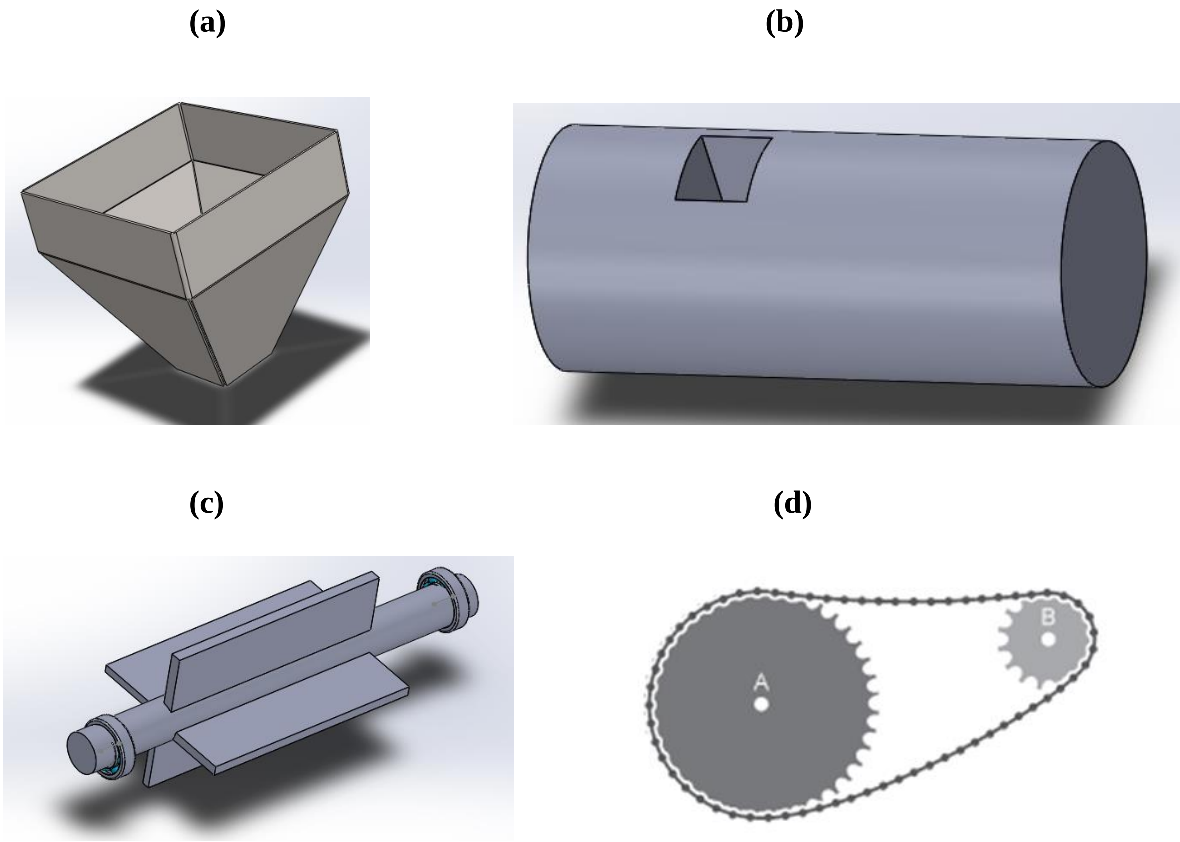


Figure 3.8: The various components of the Pedal Machine: (a) Hopper, (b) Cylinder, (c) Rotating Shaft, and (d) Sprocket and vhain drive

3.6 Material Selection using Cambridge Engineering Selector

The Cambridge Material Selector is a software package and an industry-standard tool used in engineering for material selection. It contains a large set of databases of materials from which material selection can be done and graphical method.

3.6.1 Criteria for Material Selection

The selection of the material was effectively carried out based on criteria such as stiffness, Young’s Modulus, Fatigue stress, fracture toughness, and cost, which are all relevant to the fabrication of the system. The parameters upon which the materials were selected depended on the function of the part or the component in the system. The various components of the machines for which the material selection would be applied is described in details as follows:

i. Shaft

The main important part of the system is the shaft (Fig. 3.8c). It is the rotating member of the system within the roasting cylinder, and it is responsible for providing stirring/scooping action during roasting/shea processing. Other components such as sprockets or gears (Fig. 3.8d) would be mounted on the shaft and used to transmit or transfer power from the driving device. The shaft would have a torque component. The geometrical diameter and length of the shaft should be optimized from numerical calculations and applying the factor of safety to avoid deflection or failure. The structural design of the hopper is specified by the following:

Table 3.2 Design Requirements for shaft

Function	Shaft to withstand load
Objective	Minimize mass (m) where m = Alρ, where ρ is the material density.
Constraints	1. Must be corrosion resistant 2. Must be stiff.

Performance equation can be given as:

$$\frac{F}{\delta} \geq (C_1)(\frac{El}{L^3}) \tag{3.15}$$

where δ is the maximum possible deflection, E is the Young's modulus, I is the second moment of area

Stiffness, S is given as $S = \frac{F}{\delta}$ and second moment of area, I, can be written as $I = \frac{\pi r^4}{4}$

Performance index can be written as

$$S \leq \frac{C_1 E}{L^3} \frac{A^2}{4\pi} \tag{3.16}$$

$$A = \left(\frac{4SL^3}{C_1 E}\right)^{\frac{1}{2}} \tag{3.17}$$

$$m \geq \left(\frac{4SL^3}{C_1 E}\right)^{\frac{1}{2}} \left(\frac{\rho}{E^{0.5}}\right) \tag{3.18}$$

The material index calculate in is used in the selection of materials on the chart.

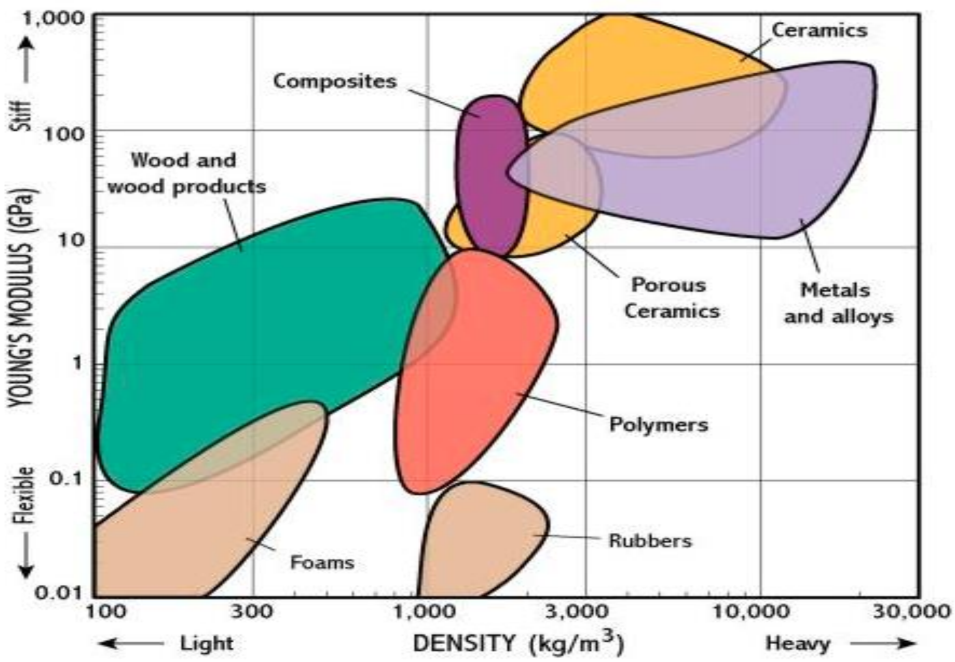


Figure 3.9. Youngs modulus vs. density

the material selection chart as shown in Fig.3.9 was used to compare and select materials suitable for the components based on stiffness. From the chart, it is observed that:

1. The heaviest materials are metals.
2. The lightest materials are foams.
3. Ceramic materials are stiffer materials.

Considering the design specifications, the shaft component needs to be light and stiff, and the chart is annotated to help find the suitable or appropriate material for the shaft. This was done by placing a selection box to show the stiff and light materials as shown in Fig 3.10.

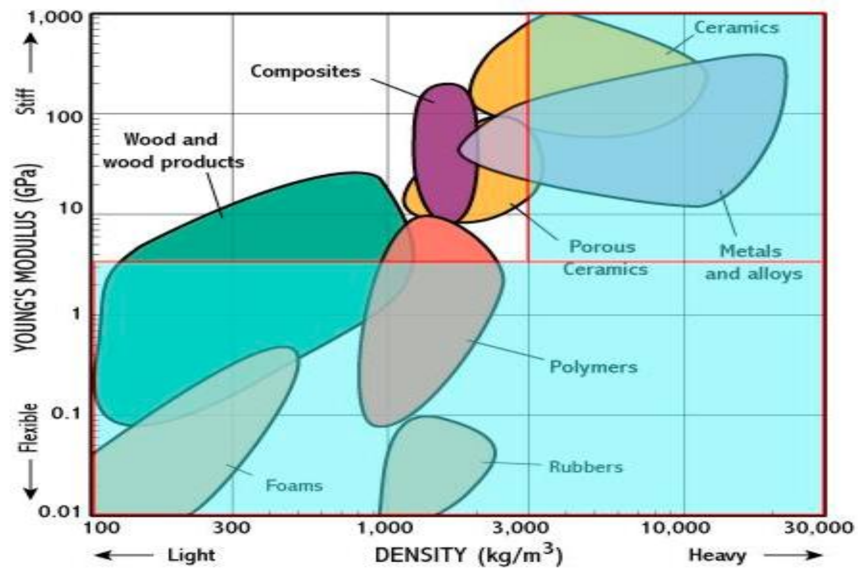


Figure 3.10 Youngs modulus vs. density

Based on the chart, it can conclude that the Young's modulus for polymer, so this means that most of the polymers are unlikely to be useful for design which are stiffness limited. Also, it can be concluded that some metals and ceramics could be considered as well as ceramics. This still leaves a lot of choice with regards to which material could be used, and therefore, it signifies that our choices should be further narrowed. In this case, the costs of the materials involved are considered as well as the strengths, as can be seen in the Figure 3.11 below.

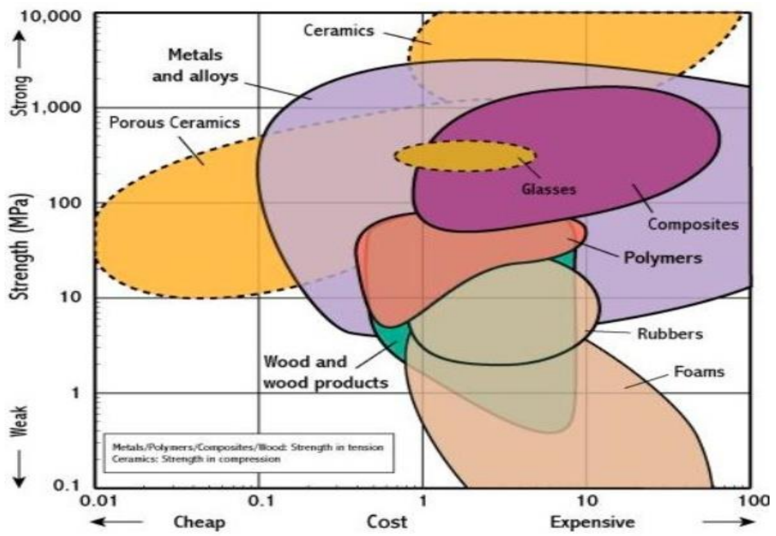


Figure 3.11 Strength vs. cost

From the graph it can be observed that ceramics are sufficient for loading actions such as compression, and they would not necessarily be strong enough in tension including bending. Also, with regards to cost, composites might be too expensive, and the strength of woods may not be as strong enough as expected. Given the reasons for not selecting wood and ceramic, the option left is metal. In the figure, metals appear to have good overall performance. In order to arrive at the suitable metal, the selection criteria are narrowed down to the metal class using the chart in Figure 3.12

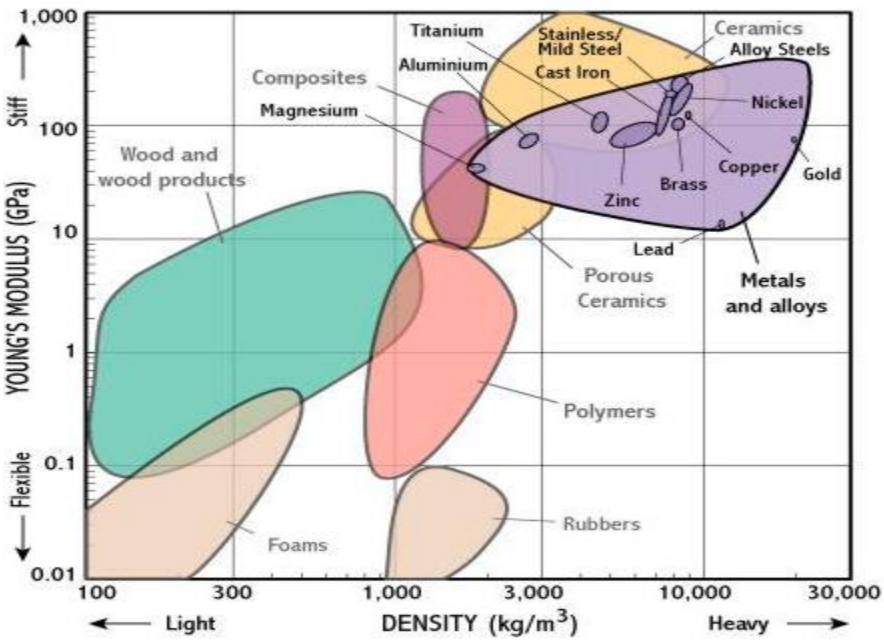


Figure 3.12 Young's modulus vs Density

From the chart above it can be observed that metals such as aluminium and magnesium are very light and can be useful for light, stiff components. Steel, on the other hand, has a relatively high density, and it is also stiff. Apart from the fact that it has high strength, its cost is relatively low as compared to the other metals. Hence based on this analysis, steel is used for the shaft.

ii. Hopper

The hopper (Fig. 3.8a) is a component of the machine that serves as the receiving point of shea nut during roasting or frying. It is needed for the efficient and effective handling of large or bulk quantities and variety of materials in their powdered form.. There are two types of hoppers: the conical and wedge-shaped hopper. While the wedge shape or flat-bottom hopper may be useful for long-term storage, the conical hopper is useful for short- and long-term storage. A major advantage of the conical hopper is the simple unloading process. In this project, the hopper needs to be designed to ensure materials flows down into the roasting cylinder in a smooth and safe manner. It should be able to handle and support the incoming load of the bulk material without failing. For this reason, the geometrical shape of the hopper is also considered because it can affect the rate of flow of the materials. The key design parameters for a hopper are; the opening diameter, the tilled angle, and the applied stress. Other material properties of the hopper that dictate the configuration of the hopper are the shea properties, cohesive strength, and bulk density. The structural design of the hopper is specified by the following:

Table 3.3 Design Requirements for Hopper

Function	Contain a load
Objective	Minimize weight
Constraints	Carry and support load without deflection

iii. Cylinder

The cylinder, as shown in (Fig. 3.8 b), serves as the compartment for roasting and frying. It is supposed to interface well with the hopper to ensure reliable flow and reasonable control over the load of materials. The key design parameters of the cylinder are; its diameter/volume, the geometrical shape, a good conductor to support heat conduction during roasting/frying, and material to resist deformation due to shea load. The structural design of the cylinder is specified by the following:

Table 3.4 Design Requirements for cylinder

Function	Contain a load
Objective	Minimize weight
Constraints	Support load without bending or deflection

The material for the cylinder must be light and strong. The material index that characterizes the performance can be calculated as follows:

$$\frac{F_{f_b}}{F_{f_b}^{o}} = \frac{16\pi I^2}{Y_m^2 A^3} = \emptyset_b^f \qquad (3.19)$$

$$A = \left(\frac{16\pi I^2}{Y_m^2 \emptyset_b^f}\right)^{\frac{1}{3}} \text{ but } \frac{I}{Y_m} = \frac{F_f L}{C\sigma_f}$$

$$A = \left(\frac{16\pi F_f^2 L^2}{C_m^2 \sigma_f^2 \emptyset_b^f}\right)^{\frac{1}{3}} \qquad (3.20)$$

$$m = \left(\frac{16\pi F_f^2 L^2}{C_m^2 \sigma_f^2 \emptyset_b^f}\right)^{\frac{1}{3}} L\rho \qquad (3.21)$$

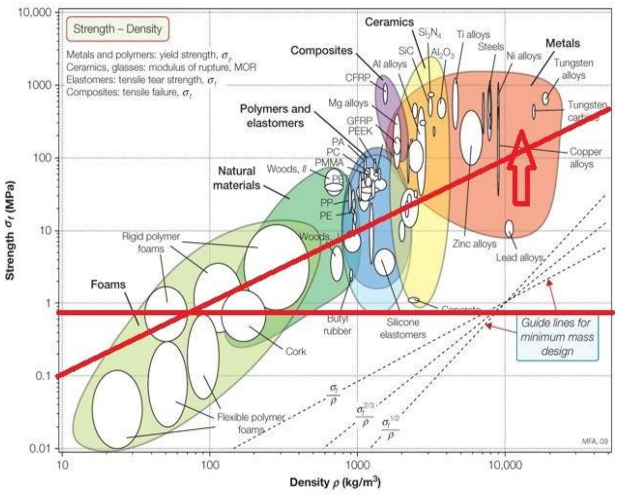


Figure 3.13: Strength vs. density

The materials above the horizontal line provide the necessary strength while the material above the left minimizes the density. Plain carbon steel is suitable for the cylinder and the hopper since they are resistant to rust over time.

Since the project aims to create a relatively low-cost pedal-powered machine, the material selected should be affordable and locally sourced. Also, the material must be easy to be machined and operated. It should also be environmentally friendly. The table below shows the source of the materials and the cost. From the material selection charts above, trade of material was made (Table 3.5)

Table 3.5: Material Selection

N	Component	Part Details	Material	Reason
1	Shaft	Diameter Distance between the Shaft and the cycle	Mild steel	High strength
2	Seat	Height of the Seat	Polymer and sponge	Comfort
4	Chain	Length	Mild steel	Cost, High Strength
5	Frame	Bicycle Frame	Mild Steel	Good service life

3.8 Fabrication Methods

The section explains the methods that would be used in the fabrication of components of the machine.

3.8.1 Cutting and Machining.

Sheet metal cutting is the process where a piece of sheet metal is separated by the application of shear force to cause it to fail. In this project, the shearing process is used to cut the metal sheet. The metal is placed into the machine so that it lies between the blades. The upper and lower blades are placed with a clearance of about 2-3% of the thickness of the material. The lower blade which remains stationary is set at a shearing angle of 3 degrees.

The shearing method of cutting is preferred to the other forms of because shearing performs a straight line without the formation of any chips or burning and melting of materials. This makes the process very efficient because there is less loss of materials Also, it is cost effective for high-output operations.

Reasons for using Shearing method.

1. It creates clean cut and smooth edges.
2. It can be performed at room temperature.
3. It is cost-effective.

3.8.2 Welding

The type of welding process used in Metal Inert Gas (MIG) welding. A continuous wire is placed through the welding gun and into the weld pool, joining the two base material together. The welding process of the various components of the system are detailed below:

a. **Welding of the Hopper**

The hopper is essentially made of four sections or walls on the side, with each side having an extra sheet of metal on top of it. All sides of the hopper are cleaned with a metal brush before striking the ark. This is done to remove rust and other surface contaminants from the metal before welding. Since most of the joints in the hopper are butt joints, the joint is bevelled to ensure the weld fully penetrates. The cable connections are tightly fitted and made sure they are free of damage. This is done to ensure an effective welding current is established when striking the ark. Since the hopper is made of steel, the cable type used is the ER7OS-3 which is and AWS classification for all-purpose welding. The gas selected for this welding is the argon (75%) and carbon dioxide (25%). This gas mixture is suitable because it produces little to no amount spatter, and it doesn’t burn through thinner metals. The gas is turned on to an optimum flow rate of 20 to 25 cubic feet per hour. The welding gun is directed to the joint at an appropriate work angle of 90 degrees to each piece before welding. The same technique is applied to each part of the hopper.

Reason for selecting MIG welding.

1. High quality welds are produced much faster.
2. It is fast.
3. It can be used with a wide variety of metals.

b. **Welding of the bicycle frame**

The type of welding used for the bicycle frame is Tungsten Inert Gas welding. TIG welding makes use of a non-consumable electrode know as a tungsten electrode, which has an extremely high melting point [24]. TIG welding works by melting the base material very much like the MIG welding. The pieces of bike frame are clamped and held in position, ready for welding. The heat is generated by an electric arc (DC) that forms between the base metal, which is the metal that makes up the two pieces to be joined. The torch is positioned at a distance of about an eighth of an inch from the surface and tipped at an angle of about 20 degrees away from the direction of travel. This allows for better visibility and of the weld puddle and accessibility of the filler material. The mixture of gas used for this welding is the argon/carbon dioxide mixture. As the welding is being done, the welds shrink as they cool, and therefore the sides are alternated in order to keep the welds even and to prevent one side of the metal from getting too hot and warping.

Reasons for selecting TIG welding

1. It offers more precision.
2. It can be operated in any position.
3. You have more control over heart produced.

3.8.3 Rolling

The rolling process consists of passing the metal through the rollers rotating in opposite directions. The 100cmx 300cm sheet of metal is passed through the gaps to be rolled. The rollers compress the metal while simultaneously shifting it forward due to the action of friction at the interface between the roller and the metal. The workpieces are considered fully worked when it completely passes through the rollers. In the process, the thickness of the sheet metal decreases while its length and width increase. Unlike hot rolling, cold rolling occurs below the recrystallization temperature of the material, usually at room temperature. This increases the strength to about 20% high through strain hardening and enhances the surface finish, and also holds tighter tolerances.

3.8.3 Estimated Cost of Materials

Table 3.6: Cost of Materials

Part Description	Quantity	Price (GHC)
Sprockets	**2**	**156**
100cm x 300 cm Galvanized steel	**1**	**275**
100cm x 300 cm carbon steel	**1**	**275**

CHAPTER FOUR

4.0 Results and Discussions

4.1 Vibrational Analysis of Cylinder

A vibrational analysis was done on the cylinder with SolidWorks Simulation Feature to identify faults within it. The vibrational analysis is based on the information content provided by the vibration signals of the cylinder. The signals provide information on the condition of the cylinder. Hence, the signals are used to diagnose faults in the system; The vibrational analysis is used to check misalignment and unbalanced forces.

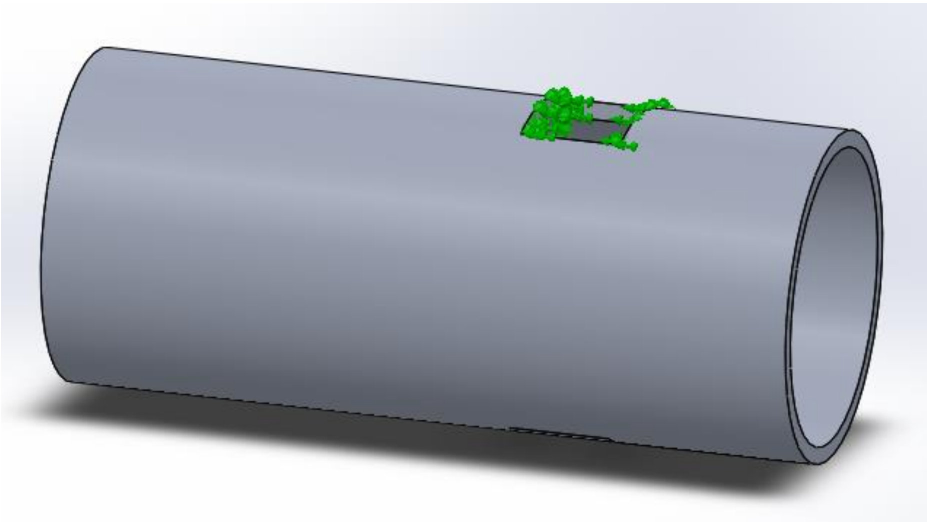


Figure 4.1: Application of fixed features to the cylinder

Five modes of vibrations were obtained at different frequencies (Fig 4.4). The first five natural frequencies were obtained for the cylinder, as shown in Table 4.1. The minimum frequency of the cylinder for each node was given, with the minimum natural frequency being 2947.5 Rad/sec and the maximum being 13449 rad/sec.

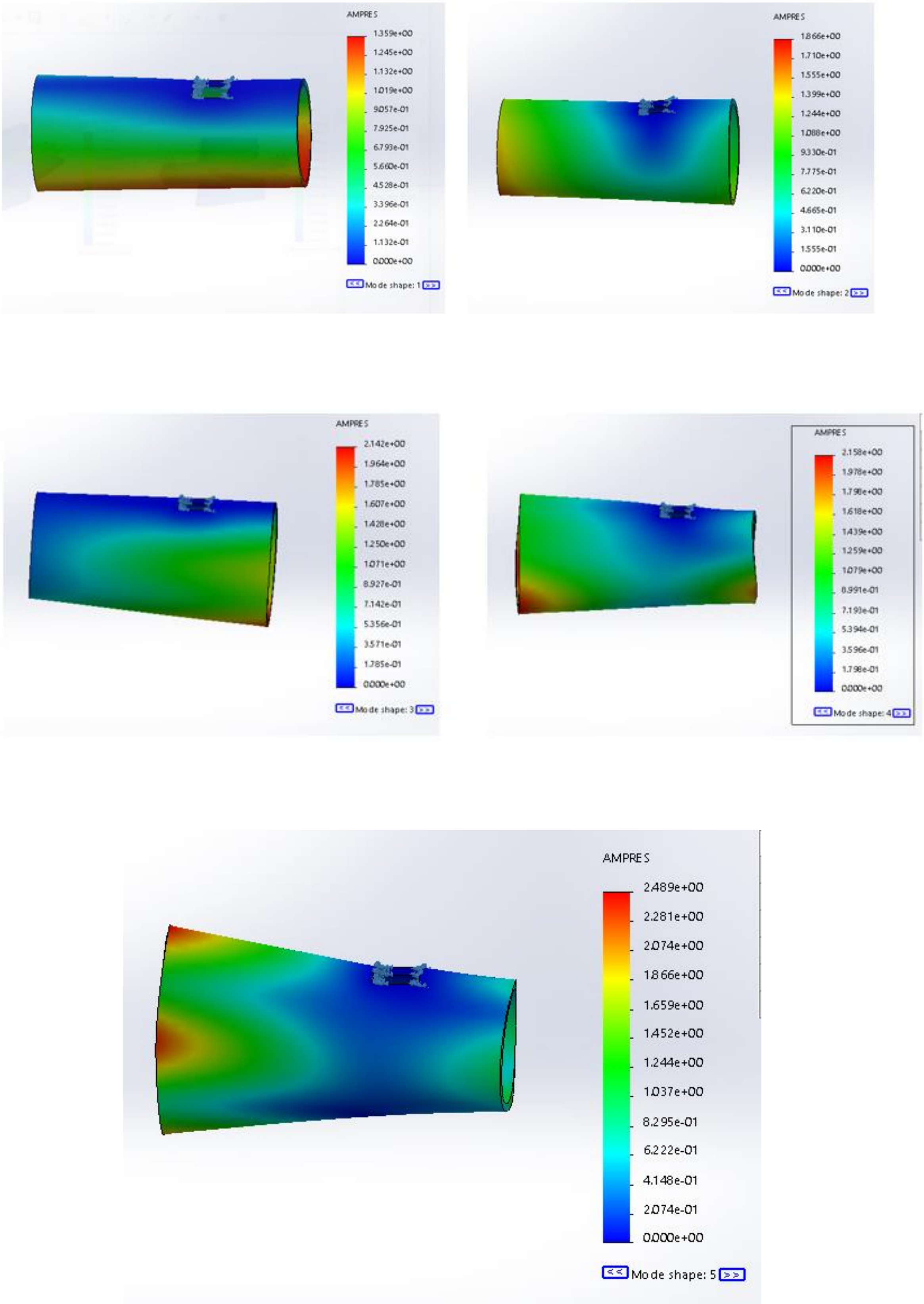


Figure 4.2: Vibrational Modes: (a) Mode 1, (b) Mode 2, (c) Mode 3, (d) Mode 4, and (e)Mode 5

Table 4.1 Natural frequencies of cylinder at each mode

Mode no.	Frequency (Rad/sec)	Frequency (Hertz)	Period(seconds)
1	2947.5	469.18	0.0021314
2	3955.3	629.51	0.0015885
3	8974.4	1428.3	0.00070013
4	9683.2	1541.1	0.00064887
5	13449	2140.5	0.00046719

The mode shapes describe the deformation that the cylinder would show when vibrating at the natural frequency. The natural frequencies and mode shapes indicate how the structure behaves under dynamic load or how it naturally displaces in response to vibration when excited at the natural frequency.

4.2 Thermal analysis of cylinder

Thermal analysis was performed on the cylinder to determine its temperature distribution upon heating. The inner temperature was set to 120 degrees Celsius, and the outer body was set to 50 degrees Celsius. Fig (4.3) shows the heat distribution of the cylinder, and it can be observed that the inner part of the cylinder is of a higher temperature than the outer part. The outer part is of a lower temperature because it cools faster since it is surrounded by the atmosphere.

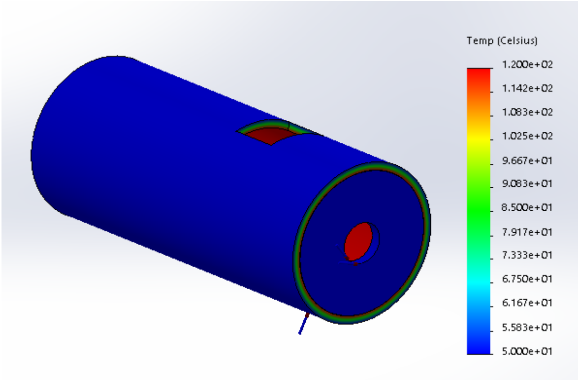


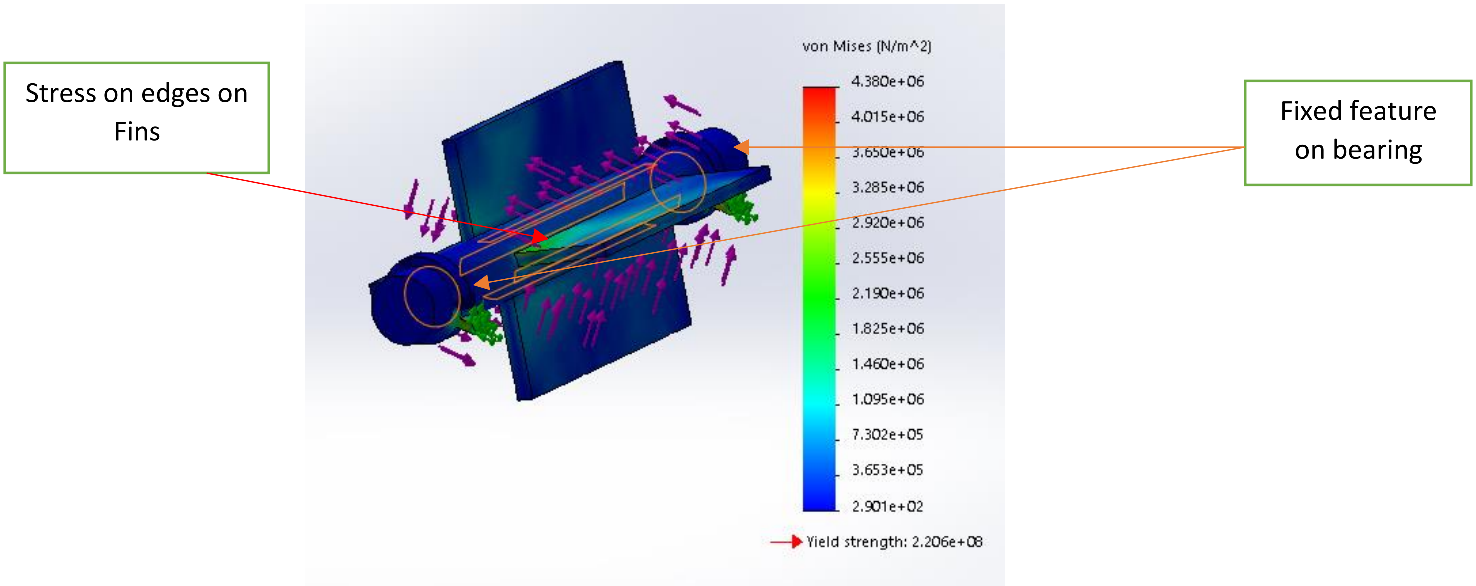
Figure 4.3: Heat distribution of cylinder

4.2 Static Stress Analysis of Shaft.

Static analysis was used to define the stress, deformation, and displacements due to static force or loading condition. It assumes that the relationship between the applied load and the structural response is linear. The main goal is to check the structure used in the machine for strength.

A 50N force and 100N force were applied to the shaft which was placed in a frictionless bearing as seen in (Fig 4.4 (a) and (b)). The fixed feature was applied on the bearing so as to make the shaft rotate freely. After the application of the 50 N load on the shaft, the maximum stress was found to be $4.380x\ 10^6\ N/m^2$. This strength was found to be below the yield strength ($2.206x\ 10^8\ N/m^2$) of the selected material (steel) for the designed shaft. Hence, the shaft will not experience plastic deformation with similar loading conditions. The application of 100N load on the same shaft led to a maximum stress of $8.760x10^6\ N/m^2$ which was also less than the stated yield stress of the material. The simulation applied on most part in the instance of the 50 N force were stresses ranging from $2.901\ x\ 10^2 N/m^2$(minimum) to $4.380x\ 10^6\ N/m^2$(maximum) whereas for the instance where 100 N was applied, the ranges of stress were from $5.802\ x\ 10^2 N/m^2$(minimum) to $8.760x10^6\ N/m^2$(maximum). In both instances of the load application, the results showed that the stresses applied to the shaft were quite high at the fins of the shaft. Increasing the load twice the initial value introduced higher stress concentrations around the fins. This suggests that in any case of potential failure, the shaft is more likely to fail around the fins. Increasing the fillets and varying the fillet radius from 5mm to 15mm helped reduce the stress around the potential failure points.

(a)



(b)

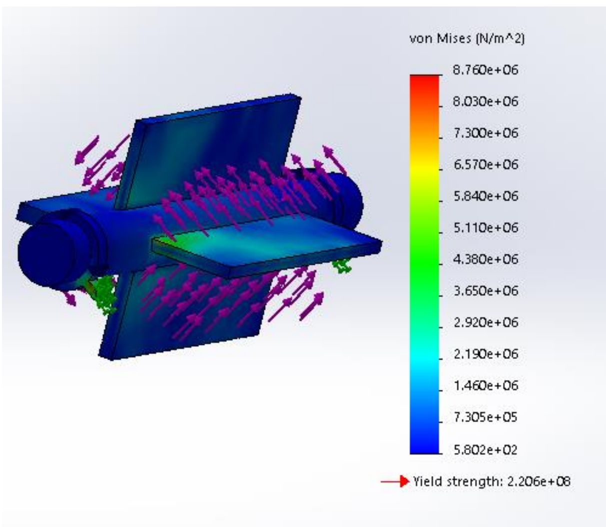
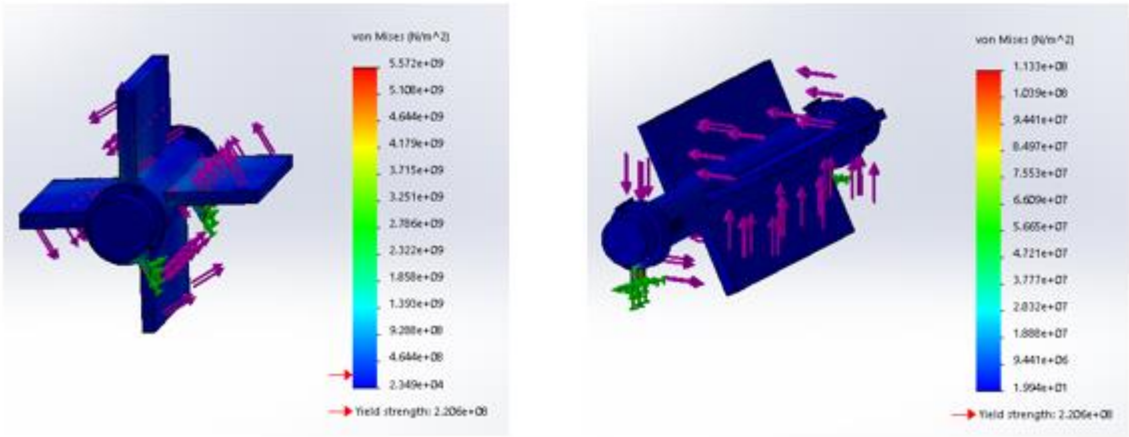


Figure 4.4: Stress Analysis of shaft: (a) at 50 N load applied, and (b) at 100 N load applied

In view of that, the simulation was also done for a range of different filter radiuses on the shaft: 0 mm filler radius, 5 mm filler radius, 10 mm filler radius, and 20 mm filler radius.

(a) (b)



(c) (d)

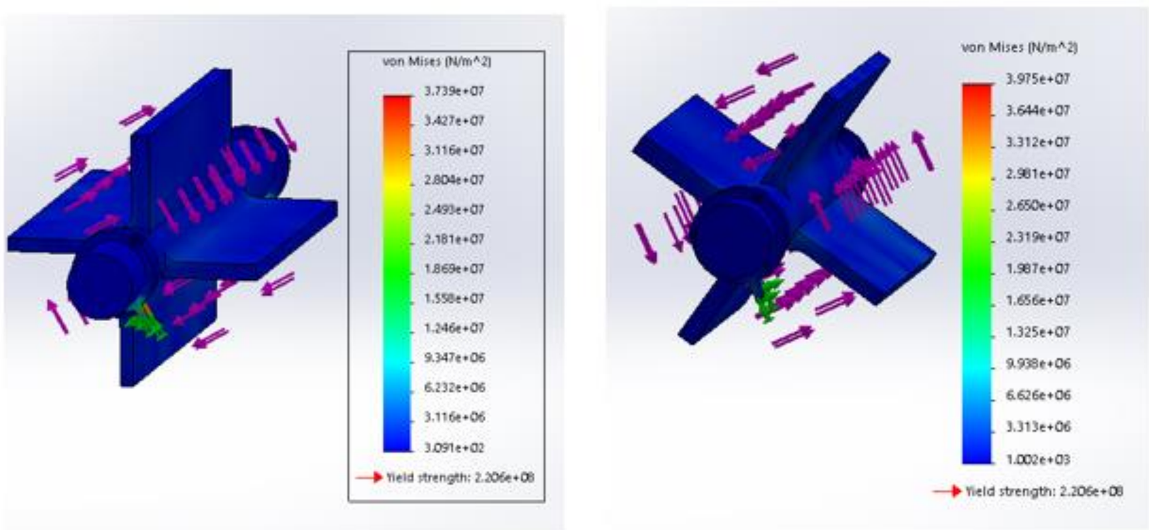


Figure 4.5: Effect of fillet radius on stress distribution of shaft at 100 N load applied: (a) 5mm filler radius, (b) 10mm filler radius, (c) 15mm filler radius, and (d) 20mm filler radius.

The minimum factor of safety obtained from the simulation is shown in Fig (4.6)

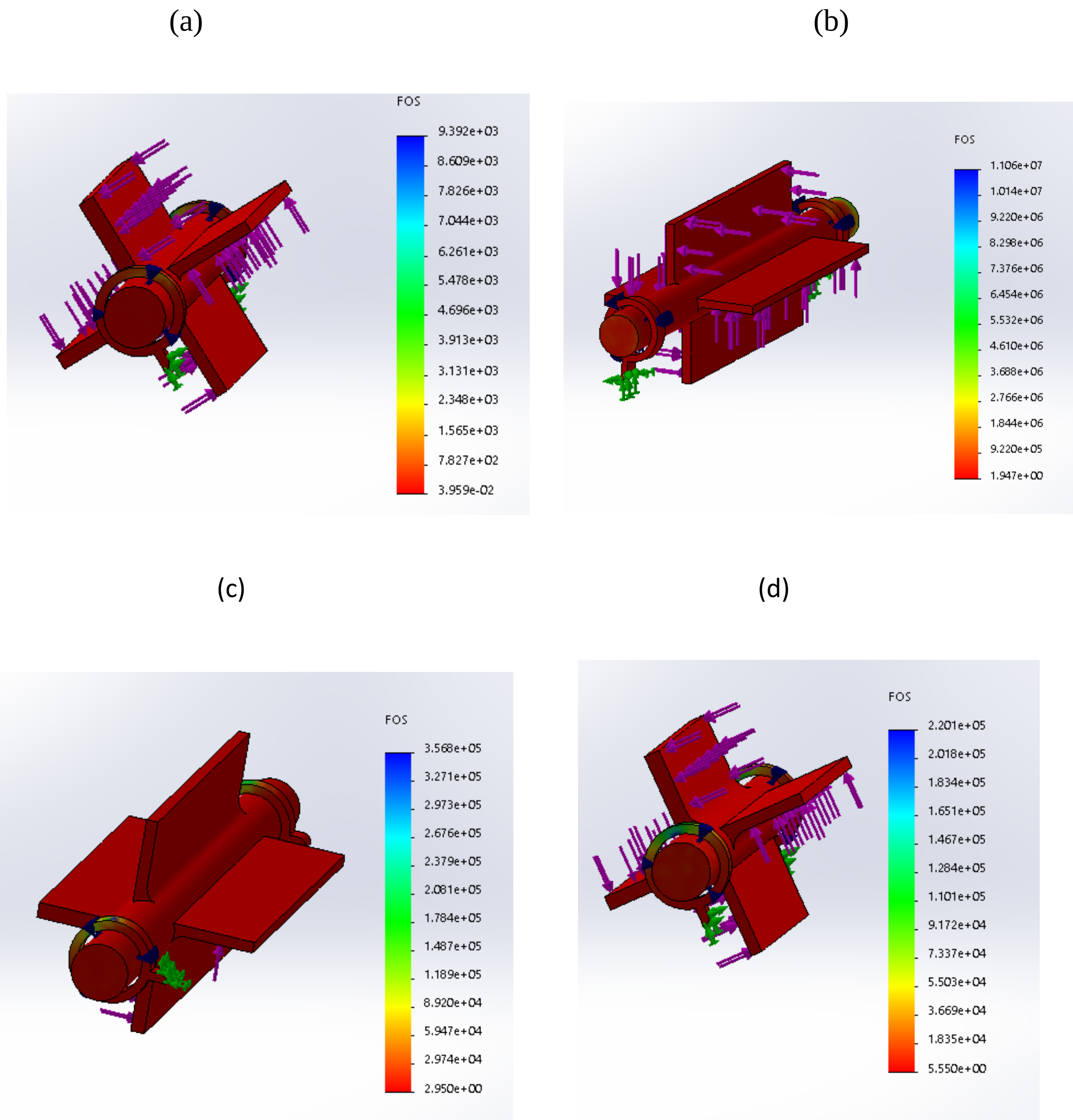


Figure 4.6: Factor of safety for stress analysis of shaft of fillet radius (a)5mm (b) 10mm (c)15mm (d)20mm.

4.3 Torsional Analysis of the shaft

A torsional analysis with a torque of 50 Nm was also performed on the shaft. The simulation was done with a different range of fillet radiuses from 0 to 20 mm. The results showed the maximum shear stresses experienced were near the edges of the fins towards the end of the shaft. From the result, it also showed that the maximum stress was between 10MPa to 18MPa, which was below the yield stress of the material, which was $2.206x\ 10^{8}\ N/m^{2}$.

(a) (b)

(c) (d)

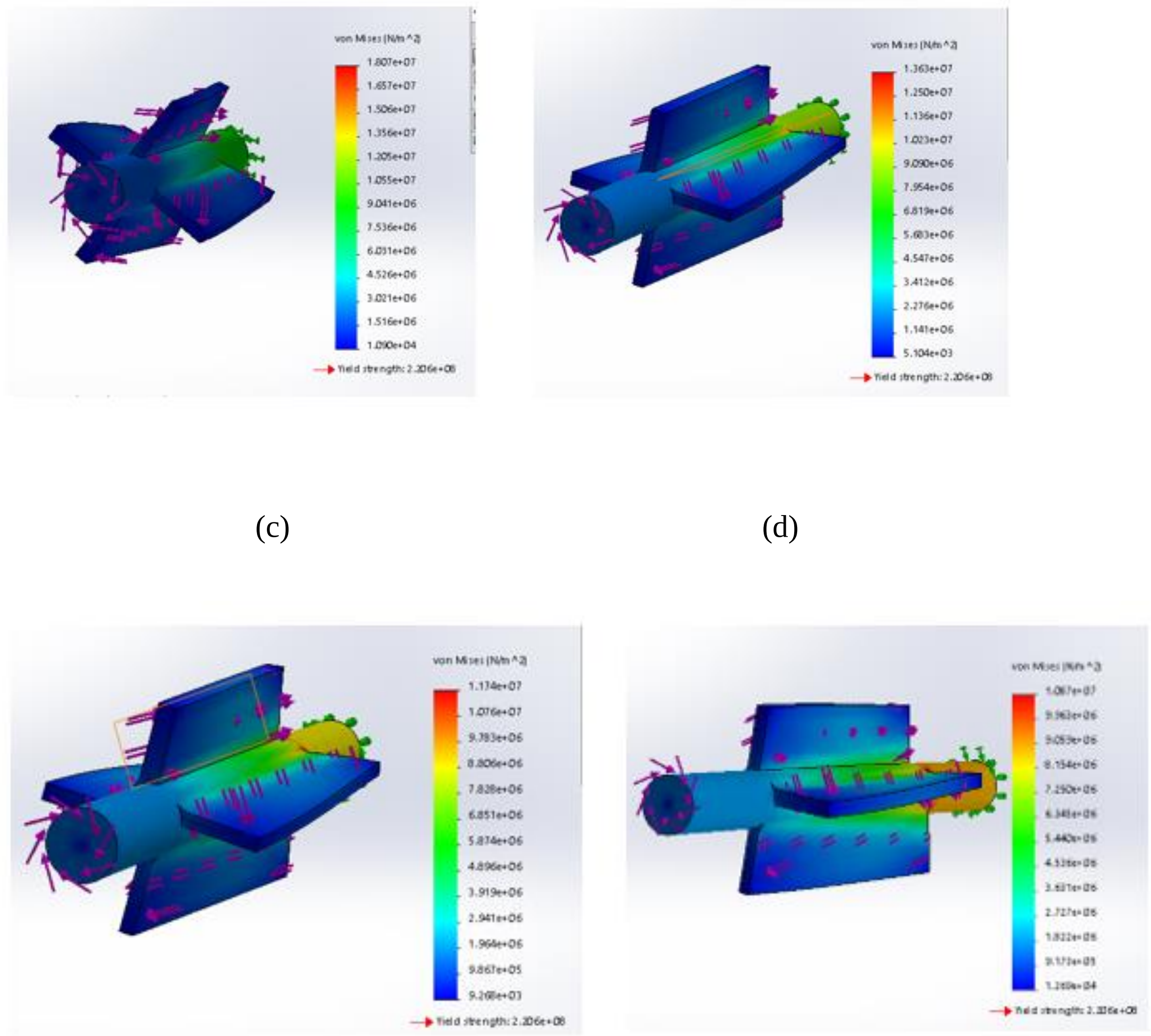


Figure 4.7: Effect of fillet radius on torsional simulation of shaft at 100 N load applied: (a) 5mm filler radius, (b) 10mm filler radius, (c) 15mm filler radius, and (d) 20mm filler radius.

In order to observe clearly the difference in the magnitude of the shear stress applied on the shaft with respect to the various fillet radius. Using the Origin Pro software, a bar graph was plotted to visualize the significant differences in the shear stress measured as can be seen in Fig. 4.8

(a) (b)

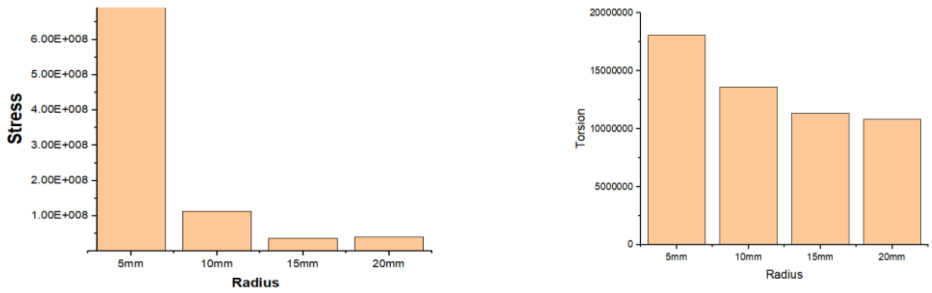


Figure 4.8: Visualizing the effect of fillet radius on (a) Static simulation and (b) torsional simulation of shaft.

From the figure, it can be seen that the introduction of fillets to the design of the shaft help to reduce the stress at points on the shaft that appeared to be susceptible to failure. On Fig.(a) there appears to be quite an extreme reduction from a shear stress of $5.532x\ 10^{9}\ N/m^{2}$ to $1.133x\ 10^{8}\ N/m^{2}$. This followed by a further reduction to $3.739x\ 10^{7}\ N/m^{2}$ and a slight increase to $3.975x\ 10^{7}\ N/m^{2}$. For Fig.(b) the graph seemed more consistent than Fig.(a).

CHAPTER FIVE

5.0 Conclusion, Remarks, and Recommendations

5.1 Conclusions

This project aimed at the design of a pedal-powered machine to enhance shear nut processing. Three design concepts were considered and subjected to various criteria after which the second design concept was eventually chosen as the final design.

Several simulations and analyses (static, torsional, and vibrational) were performed on some components of the machine. The result obtained from the static simulation of the shaft showed that the places susceptible to failure were the edges of the fins on the body of the shaft. Fillets of various radiuses were applied on the shaft, and it was observed that the stress distribution at that area reduced considerably. The result from the vibrational analysis of the cylinder showed the various modes of displacements the cylinder will be subjected to at resonance frequency.

5.2 Limitations

The project faced a variety of challenges and limitations in the process. A significant number of challenges can be attributed to the simulation in SolidWorks. The simulation of some components, such as the bike frame, was not done to the end owing to the intermittent crashing of the SolidWorks software.

Another limitation was the inability of the project to be fully built and test it. This was primarily due to the lockdown that was resulted from the coronavirus.

5.3 Future Works

Given the limitations, some significant design and functional improvements can be made to the project, especially if it is to be considered for commercial purposes in the future. The cylinder can be manufactured with a material with a higher damping capacity, such as gray cast iron. This would help induce or absorb unwanted vibrations during operations. It would also prevent the cylinder from deformation, which can affect the functionality.

Also, another improvement can be made on the height of the bicycle seat post. The seat post can be made adjustable in order to accommodate people of different heights and preferences.

Lastly, the fabrication of the entire machine is also one of the future works considered.

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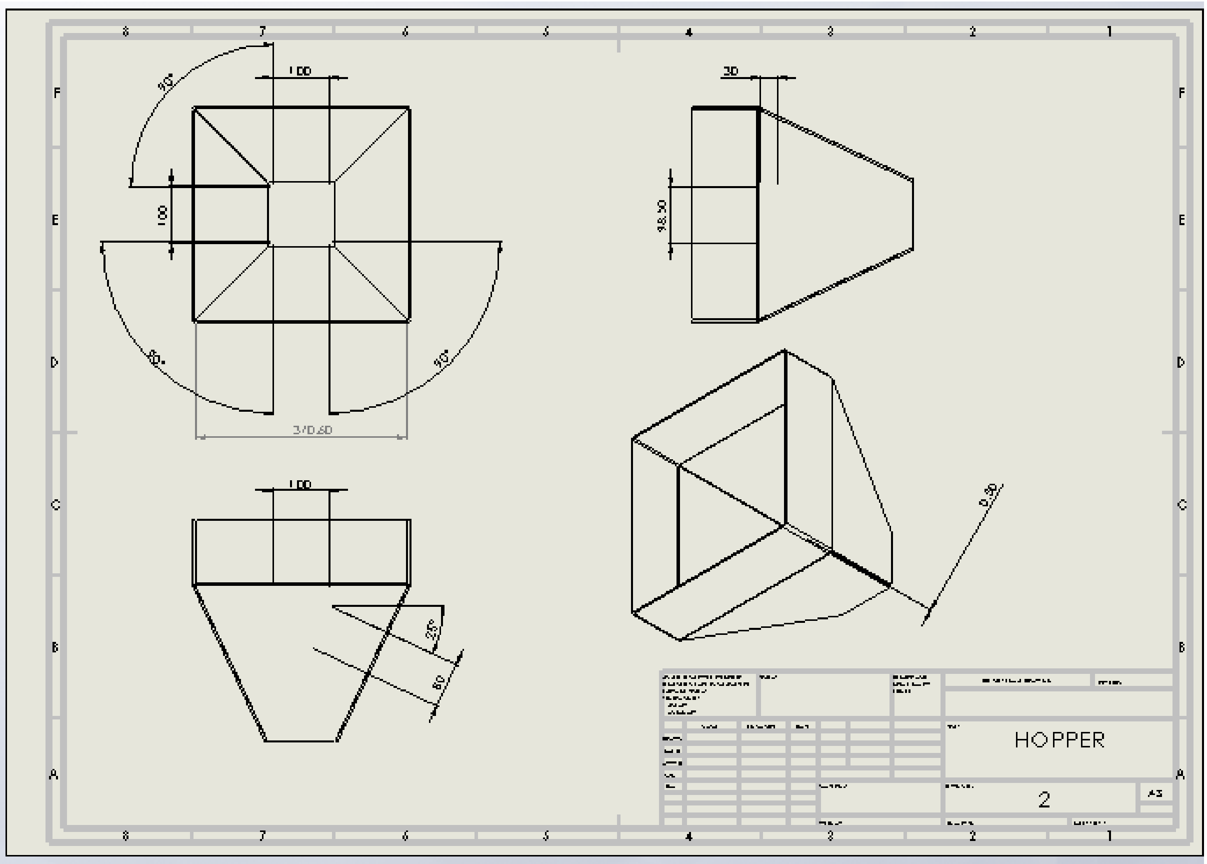
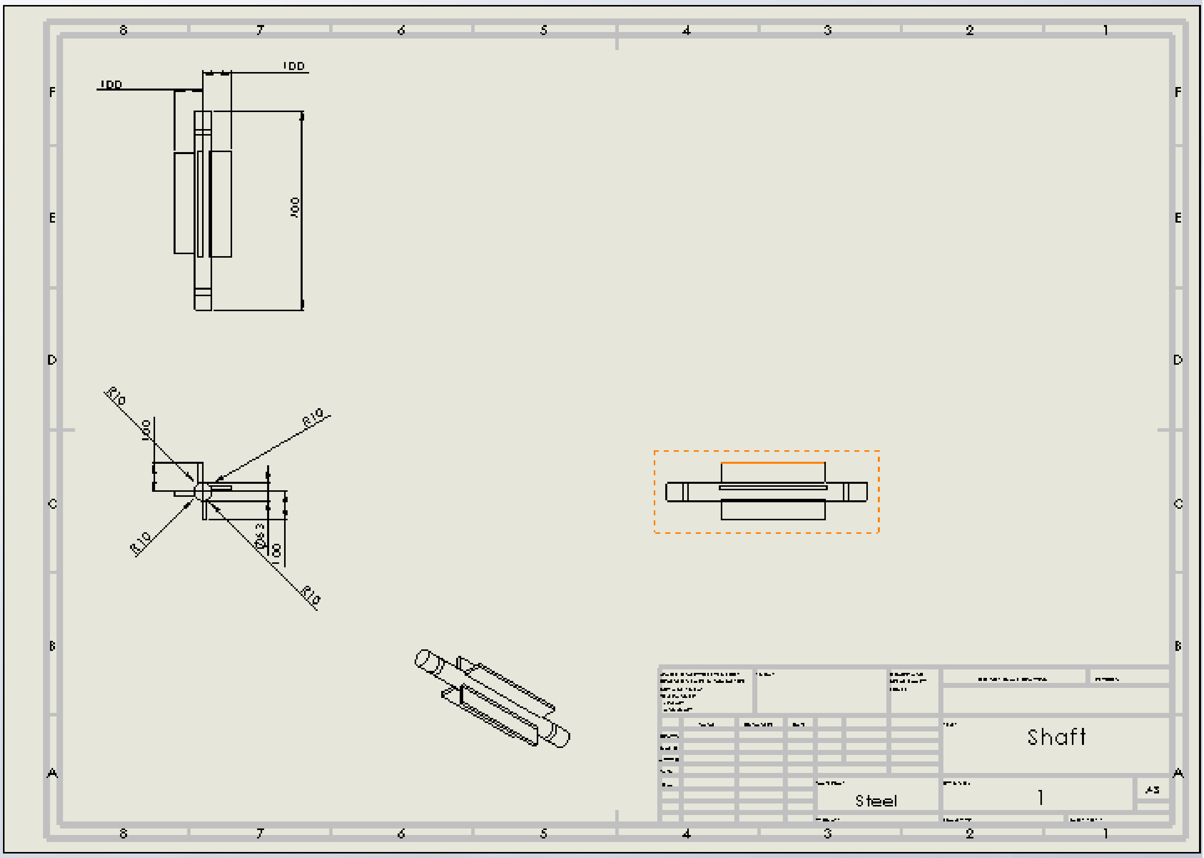
Appendix

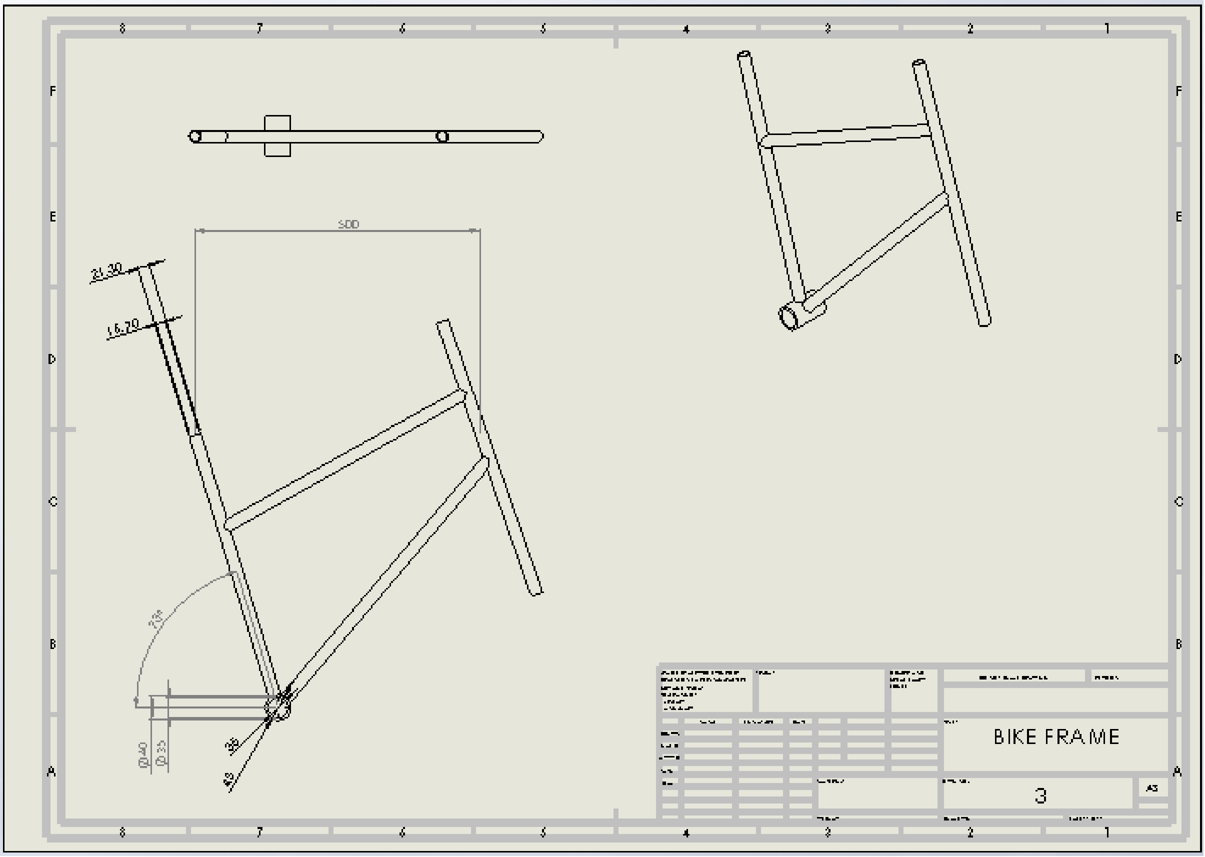
Appendix A: Drawings of Hopper.



Appendix B: Drawings of Shaft.



Appendix B: Drawings of Bike Frame.



Appendix B: Drawings of Cylinder.