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Original Article

Design, Manufacturing and Performance Evaluation of Jatropha Seed Oil Extracting Machine

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Abstract - *Jatropha is one of the most notable biodiesel crops in the universe. This research displays the design and performance assessment of a prototype constructed for extracting oils from jatropha seed as an adequate energy demand of the people and local industries for oil needs in a simple, low-cost and less time taking method. The design was sectioned into the hopper and chamber, the stand support and the power delivery mechanisms. The seed processing unit comprises the top and bottom body where the hopper, screw shaft and chamber are sealed off. The prototype is driven by a 3 kW 750 rpm electric motor by a V-belt system which liberators the power needed to the screw shaft on which the chamber is mounted. The chamber presses the processed seed along the screw shaft to extract the oil. The jatropha seed is fed into the chamber for processing within the hopper. The possible failure of the prototype during loading has been decreased by suitable material selection and using a factor of safety of 4 in the design process. The prototype was aimed to process about 120 kg/h of jatropha seed for small-scale manufacture. Performance assessment of the model displays that its efficiency is between the ranges of 92.59 to 98.04%, the extraction capacity is the same (120 kg/h) for three test runs, and the efficiency is maximum at 9 kg processed seed since the assumed oil content of the seed is minimum at this experiment.*

Keywords - *Jatropha seed, Biodiesel, Performance assessment, Design and Prototype.*

1. Introduction

The alternative oil industry is growing quickly due to high crude expenses and increasing concerns about global climate change. Ethanol from sugarcane in Brazil and corn in the United States and biofuel from rapeseed in European Union countries have been well marketed as crude oils and attracted the government's attention. In Africa, the jatropha is well-planned to be one of the most candidates for biofuel processing plants because of its good behaviour in semi-arid and arid lands [1]. The oil content of the processing plant seed ranges from 32% to 40%; the average is 34 percent. The Jatropha seed contains various toxins, and this plant seed cake is non-edible [2], [3]. Jatropha can be cultivated with a profitable income. The seeds of jatropha contain 50-60% oil [4]. In this regard, this research focuses on the design and construction of a prototype of the Jatropha oil extraction machine, as well as testing the performance evaluation of the developed machine.

1.1. Problem Statement

Environmental pollution is on the current international agenda. It is being a great headache for developing as well as developed countries. Moreover, the cost of production and distribution of fossil fuels is also a great challenge for a country like Ethiopia. Thus, an alternative to conventional fossil fuel is a major issue to satisfy the growing energy demand of the country.

Fig. 1 Jatropha plant

Fig. 2 Jatropha seeds and jatropha kernels

Extraction of biodiesel from jatropha in Ethiopia is a new technology and facing many challenges because of the lack of proper facilities such as pealing machines and oil extraction machines which are useful in the production of biofuels in

Ethiopia. Although the extraction and usage of jatropha oil have been realized in some parts of the world, appropriate engineering data on extraction, design and process evaluation are still lacking and need to be addressed. Therefore, this research tries to develop a machine that extracts biofuel from the jatropha plant.

1.2. Objectives of the Study

1.2.1. General Objective

The main objective of this research project is to design and manufacture a Jatropha seed oil extraction machine.

1.2.2. Specific Objective

- To conduct mechanical analysis of the components (shafts, screws, bolts, bearings) of the machine.
- To perform mathematical simulations using ANSYS software
- To compare both results and develop the working machine accordingly

2. Materials and Methods

2.1. Different Screw Shaft Arrangements

A screw shaft is used for crushing different seeds among the screw press and the press chamber to refine the oil. It has been recycled in liquid-solid differentiation of refining jatropha oil machine intentionally to distinguish between cake and oil. Here various shapes have been clarified to attain the best design performances in a screw press.

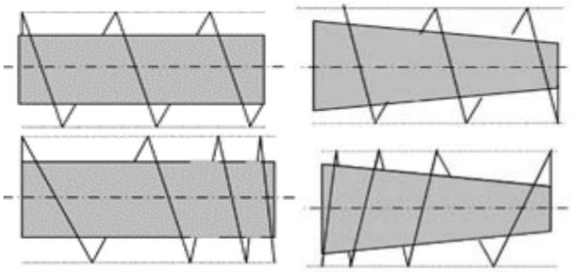


Fig. 3 Straight screw shaft arrangement, tapered shaft and continuous pitch screw configuration, variable pitch screw, tapered shaft and variable pitch screw [60]

The significant considerations are documented here to design and calculate the volume of the desirable seed-pressing chamber.

Dc=100 mm=0.1 m = the press chamber diameter

Rc =Dc/2=50 mm=0.05 m = the radius of press chamber

Lc=400 mm=0.4 m = the length of the press chamber

B=7 mm=0.007m = the breadth of filament on the screw winding

The geometric mean diameter, Dg, of the jatropha seed ranges between 10.15mm=0.01015m to 12.72 mm=0.01272 m. The filament pitch should be able to accommodate all the ranges of Dg of jatropha seed [62];

P=20 mm=0.02 m = the pitch of the filament

Given that the mild steel of a screw shaft with external (major or nominal) diameter, d=90 mm=0.09 m

r=d/2=45 mm=0.045 m = the nominal radius of the screw chamber

tcw =10 mm=0.01 m = the chamber wall thickness

dr=80 mm=0.08 m = the minor diameter of the screw shaft

rr=d_r/2=40 mm=0.04 m = the core radius of the screw shaft

t=10 mm=0.01 m = the screw winding thickness

L_s=390 mm=0.39 m = the length enclosed by the screw shaft

N = the total number of screw windings must be the whole number on the screw shaft

N= (390 mm)/(7 mm+20 mm)=14.44≈15 Windings

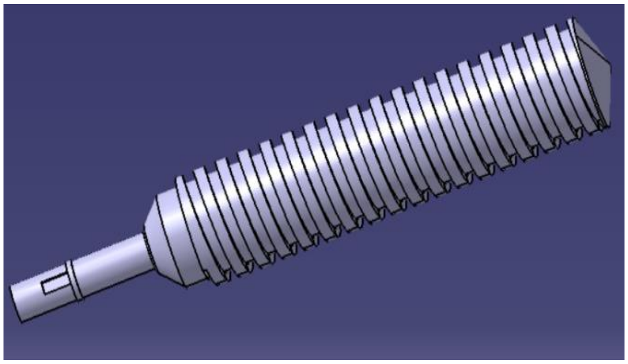


Fig. 4 Screw shaft modelled by CATIA-V5

Taking into consideration the formula of the circumference of a circle was used to determine the length of a screw winding.

2.2. Design of Screw Shaft

To design the shaft on which the two pulleys are mounted, here we will consider factors that manifest in practical application. Consequently, in order to design our shaft, the combined shock and fatigue factors must be taken into account for the computing twisting moment T and bending moment M.

As we can see on the force analysis and torque diagram, the load applied on the pulley, and the torque applied on the bearing is no more than the force and torque applied on the previous shaft 1. Therefore, considering this fact, it is possible to make the diameter of the two shafts equal, which is 30 mm.

Performance Investigation Techniques of the Developed Machine are conducted and discussed later.

2.3. Prototype Development

The developed jatropha seed oil extraction machine is prototyped with materials, manufacturing methods and apparatus. Table 3-9 displays the material, manufacturing ways and apparatus used in the developed prototype of the oil extraction machine.

Fig. 5 Final assembly model by CATIA-V5, manufactured prototype

The machine was designed and developed to extract biodiesel from jatropha seed. This machine is made up of stands, a hopper, a chamber, power transmission components such as shafts, pulleys, belts, and an electric motor. In the Wolaita Sodo University of electrical lab, a 4hp motor is available, and we are used as a power source to test the performance of the prototype due to a shortage of money to purchase the source. The power is conveyed from the engine to the screw shaft through double-stage pulley-belt systems. The overall specifications of the developed machine have a total length of 974 mm, height of 410 mm and breadth of 503 mm with a motor of 3 kW, labour needed is one woman/man, and it is safe and easy to operate.

The stands: the chamber stand is made of a 40×40 mm square bar welded with a 60×40 mm rectangular bar. The total dimension was 130 mm in length, 410 mm in height and 347 mm wide. The intermediate shaft stand is made of a 40×40 mm square bar welded with a 60×40 mm rectangular bar, and the entire dimension was 182 mm long, 170 mm high, and 116 mm wide. The motor stand is made of a 60×40 mm rectangular bar welded with a 40×40 mm square bar, and the entire dimension was 309 mm in length, 347 mm wide and 196 mm high. The stand holds other machine components, such as the motor, hopper, chamber and shafts and pulleys.

2.4. Experimental Methodology and Techniques

After the design and manufacturing of the prototype, testing is crucial in the way of machine development. It is obligatory to realize the prototype's performance, report mistakes and areas of potential advance and emphasize the achievement level of the research. Thus, examining the performance of the prototype is implemented with a number of parameters. The performance parameters for our investigation are biodiesel yield (oil refining ratio), oil refining efficiency, the capacity of the prototype in tones of bundles/h, and efficiency of seed discharge in % of the jatropha seed were computed accordingly [67].

$$\text{Oil yield}=(\text{Mass of extracted oil})/(\text{Mass of seed bundles feed})\times 100$$

$$\text{Oil yield} =(1\ \text{kg})/(3\ \text{kg})\times 100=33.33\% \quad [67]$$

$$\text{Oil refining efficiency} = (\text{Mass of oil extracted})/(\text{Total expected oil})\times 100$$

$$\text{Oil refining efficiency}=(\text{Mass of oil extracted})/(\text{Mass of seed proposed [kg]}\times\text{Oil content of seed})\times 100$$

$$\text{Oil refining efficiency}=(1\ \text{kg})/(3\ \text{kg}\times 0.36)\times 100=92.59\%$$

$$\text{Machine capacity}=(\text{Mass of seed bundles})/(\text{Sampling time})$$

$$\text{Machine capacity} = (3\ \text{kg})/(1.5\ \text{min})=2\ \text{kg/min} =120\ \text{kg/h}$$

To investigate and synthesize the facts from the experiment, 120 kg of Jatropha seed sample was collected from a Jatropha plant used as a living fence by farmers around farms, fields and gardens of Ethiopia in Omo Lante near Arbaminch and separated into three exploration samples of 3, 6 and 9 kg measuring with a mass weighing scale to conduct the experiments for each sample. This might be aimed at relating the prototype's performance with the previously designed machine. Each experiment sample was fed into a hopper of the feeding system to feed the developed machine constantly in the given time.

The conducted three tests were extracting the oil with the oil exit for each trial was gathered in the reservoir and measured with a mass weighing scale, and the obtained outcome was recorded. This was important to obtain the prototype's efficiency using the formula intended in equation (4.44). The scholars informed that the machine's efficiency differs from seed to seed since the oil content of the seed depends on the climate/soil conditions. Abelmutalab F. Kheiralla et al. [41], [68] informed the mechanical expeller oil extraction efficiency was 85%, [69] reported that the mechanical oil extraction machine has an efficiency of 89.4%, [22] reported the efficiency of the mechanical expeller was 86-92%, and [54] informed the oil recovery rate of the machine was up to 90 to 95%.

The de-oiled meal is an appreciated source of protein for feeds of animals and is discharged at the end of the chamber, then measured with a mass weighing scale, and the result was recorded. This was significant in getting the extraction loss of the prototype.

3. Result and Discussion

This chapter comprises all the outcomes and discussions of the jatropha seed oil extraction machine's design, manufacture and performance investigation. The analysis results obtained in ANSYS are compared with analytical values, permissible results, and other research findings for validation. The outcomes were shown in the figure, table and graphical representation.

3.1. Performance Evaluation Results

In demonstrating the performance assessment of the constructed oil extraction machine of jatropha seed, three experiment runs were implemented on the machine. The hopper was intended for a maximum of 10 kg of jatropha seed. Various weights of unhusked jatropha seed were entered per time. The mass of processed jatropha seed, the mass of extracted oil, the average oil content of jatropha seeds, the time occupied, as well as efficiency of oil extraction are detailed in Table I and Figure 6.

The prototype does not crush fast when beginning from rest; it collects momentum first and is overloaded ahead. It creates the use of both gradual loadings as well as gravitational movements of Jatropha seed during extraction.

Table 1. Displays the outcomes of the three experiments

Test	**Processed seed (kg)**	**Extracted oil (kg)**	**Average oil content of the seed (%)**	**The time occupied (min)**	**Extraction efficiency (%)**
1	3	1	36	1.5	92.59
2	6	2	35	3	95.24
3	9	3	34	4.5	98.04

Experiments run on the manufactured Jatropha oil extraction machine with 3, 6 and 9 kg of Jatropha seeds. As presented in Table I, the extraction efficiency rises from 92.59 to 98.02%, whereas the average oil content of jatropha seeds percentage drops from 36 to 34% as the mass of processed seed rises from 3 to 9 kg. The oil extraction efficiency rises by 98.04%.

The percentage oil content of Jatropha seed decreases to 2% as the mass of Jatropha seed loaded rises from 3 to 9 kg. The oil extraction efficiency of the machine is maximum, but the percentage of oil content of Jatropha seed is minimum at 9 kg processed seed.

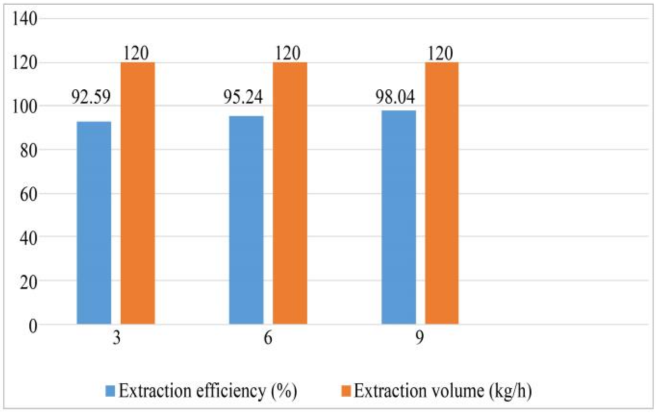


Fig. 6 Processed seed into a hopper (kg) vs Extraction efficiency (%) and volume (%)

Table 2. Component analysis outcomes of the developed machine

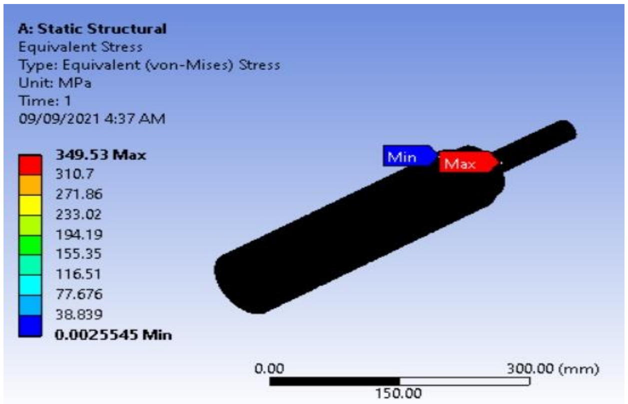
Elements		**Apparatus (materials) used**	**Sizes**
Stand	Chamber	Low carbon steel	130 mm×340 mm×265 mm
	Intermediate shaft		182 mm×170 mm×116 mm
	Motor		309 mm×196 mm×347 mm
Pulleys	Driven	Steel	Ø 300 mm
	Driving		Ø 85 mm
Belts	Motor to the intermediate shaft	Leather	505 mm
	Intermediate to screw shaft		
Shaft	Intermediate	Low carbon steel	116 mm
	screw		522 mm
Nuts and bolts		Steel	M_8
			M_{15}
			M_5
Bearing	Intermediate shaft	Steel	Bore Ø 30 mm Outside Ø 62 mm Width 16 mm
	Screw shaft		
Hopper	Top	Galvanized steel	370 mm×65 mm×360 mm
	Middle		260 mm height
	Bottom		100 mm×70 mm×100 mm

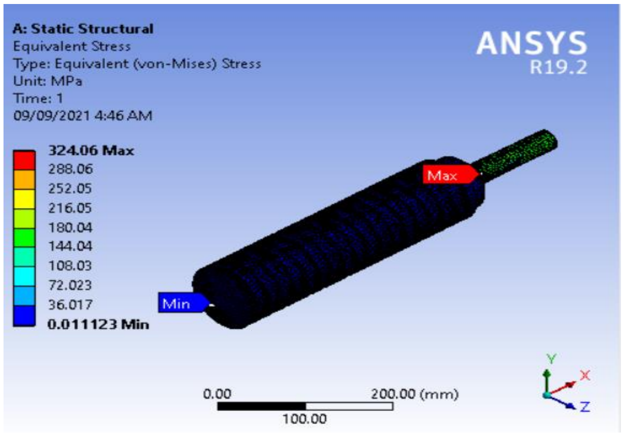
This indicates that the rise in the amount of processed seed up to 9 kg makes to subject the screw shaft to such a loading which in turn reduces the extraction process and is accountable for the minor extra amount of processed seed that crashes and that which escapes the squeezing route among the chamber and screw press. As presented in Figure 4.2, the extraction volume is the same for 9, 6 and 3 kg loading (120 kg/h or 2kg/min). Though in constant production, it has been realized that processed seed in kg/h indicated the same labour productivity as it keeps a balance between time occupied and the amount of time desired for the machinist to fill up the hopper with processed seed.

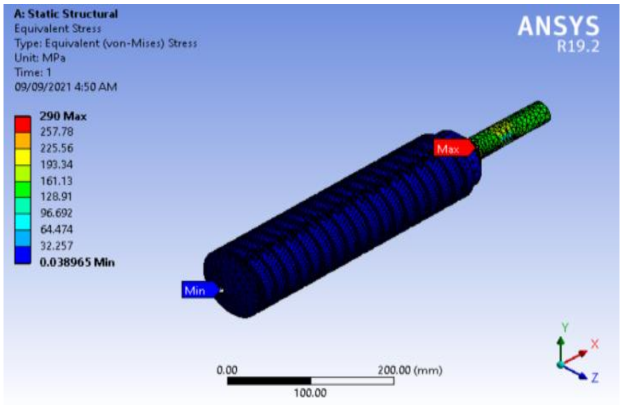
3.2. Investigation of Design Outcomes

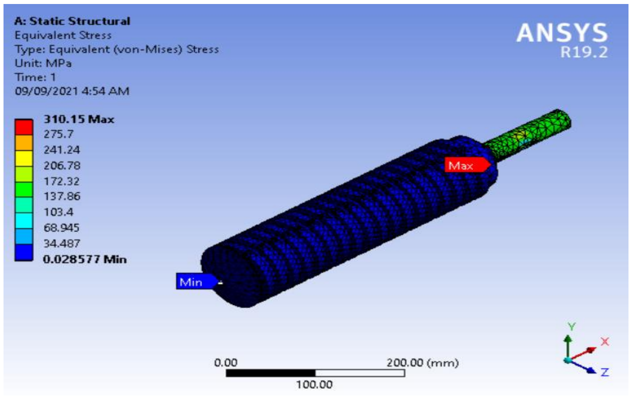
In chapter three, the design of mechanisms, numerical assessments of sizes, stress and force, material selection and other calculations were achieved. These outcomes are displayed and explained in this subtopic.

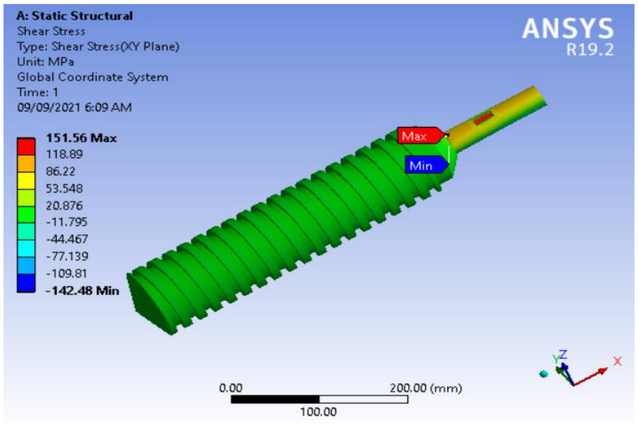
Table II presents the component stage design results of the biofuel extraction machine from jatropha seed. The sizes, apparatuses and amount of elements were based on several design attentions such as obtainability of apparatuses, load, cost and ease of use of the prototype. Components of this machine were branded by their designed sizes, tools and amounts.

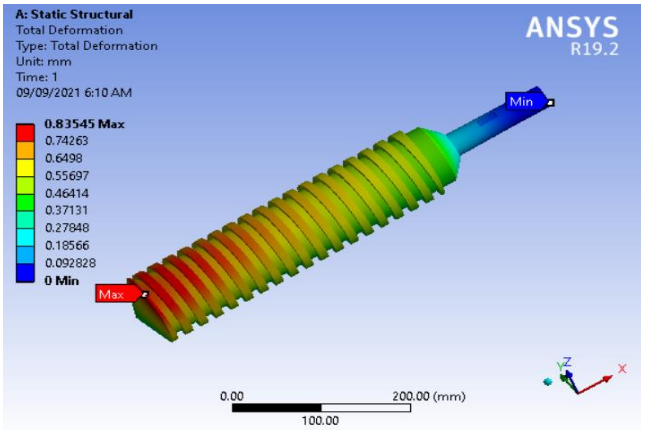












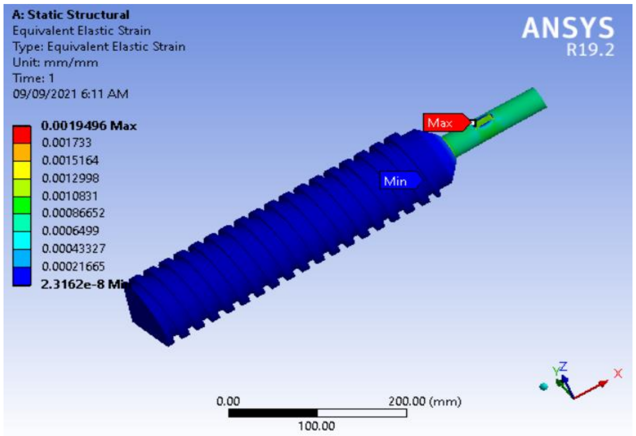


Fig. 7 Screw shaft mechanical

3.3. Analysis is done by ANSYS Software

The results realized from the ANSYS 19.2 mechanical workbench showed the effect of stress and deformation on the shaft material. The analysis was performed by varying the mesh size and using the mechanical properties of the selected screw shaft material. The gravitation weight, tensions on the belt and pulley weight are the applied loads on the screw shaft during the analysis. The analysis technique outcomes are discussed in detail in the next subsection.

3.4. Equivalent and Maximum Shear Stress Outcomes of Screw Shaft

After giving all the desired data for analysis in static structure, a stress tool is preferred to tell outcomes for maximum shearing and equivalent stress for a given loading condition. In ANSYS analysis, the outlines and animation display the successful achievement of the solving process to get insights on the shaft performance at fixed boundary conditions. Ever since, the analysis was done by considering various loading cases, and their outcomes were planned, including stress outlines in each shaft component with the maximum and minimum extent of stresses under each loading condition. Therefore, the stress results shown for the deliberated analysis of different mesh sizes are discussed in detail as follows.

As shown in Figure 7 above, we analysed the equivalent stress by ANSYS 19.2 mechanical workbench and compared all the results obtained in each step. As presented in Figure 4-3, we analysed that the equivalent stress occurred at the bearing support due to the belt tensions and pulley weight producing maximum stress (349.53 MPa) on the screw shaft. From this analysis, we have decided the assessment of equivalent stress indicates that the shaft does not break under applied load in relation to Von-Mises Theory; that means since the assessment of tensile strength of the shaft material is greater than that of the software analysis of Von-Mises stress (450 MPa>349.53 MPa).

Similarly, as presented in Figure 7, the maximum shear stress (151.56 MPa) happens at the same place as a result of pulley weight and belt tensions. Additionally, the assessment implies that the ultimate shear strength of the shaft material is greater than that of the software analysis of maximum shear stress (250 MPa>151.56 MPa). From this result and along with the Maximum Shear Stress Theory, the screw shaft does not fail under the applied load. Furthermore, in Figures 4-8, the total deformation is maximum (0.83545 mm) at the other end of the screw shaft where there is high friction. The total distortion of the screw shaft is in a safe range compared to the material elongation.

3.5. Equivalent and Maximum Shear Stress Outcomes of Intermediate Shaft

After giving all the desired data for analysis in static structure, a stress tool is preferred to tell outcomes for maximum shearing and equivalent stress for a given loading condition. In ANSYS analysis, the outlines and animation display the successful achievement of the solving process to get insights on shaft performance at fixed boundary conditions. Ever since, the analysis was done by considering various loading cases, and their outcomes were planned, including stress outlines in each shaft component with maximum and minimum extents of stresses under each loading condition. Therefore, the stress results shown for the deliberated analysis of different mesh sizes are discussed in detail as follows.

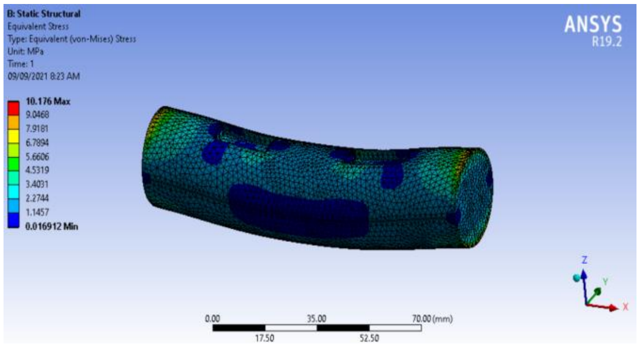


Fig. 8 Intermediate shaft analysis of equivalent stress when the mesh size is 1 mm

As shown in Figure 8, we analyzed the equivalent stress by ANSYS 19.2 mechanical workbench and compared all the results obtained in each step. As presented in Figure 4.10, we also analyzed that the equivalent stress occurred at the bearing support due to the belt tensions and pulley weight producing maximum stress (10.176 MPa) on the intermediate shaft. From this analysis, we sum up the assessment of the equivalent stress, indicating that the shaft does not break under applied load in relation to Von-Mises Theory; that means since the assessment of tensile strength of the shaft material is greater than that of software analysis of Von-Mises stress (250 MPa>>10.176 MPa).

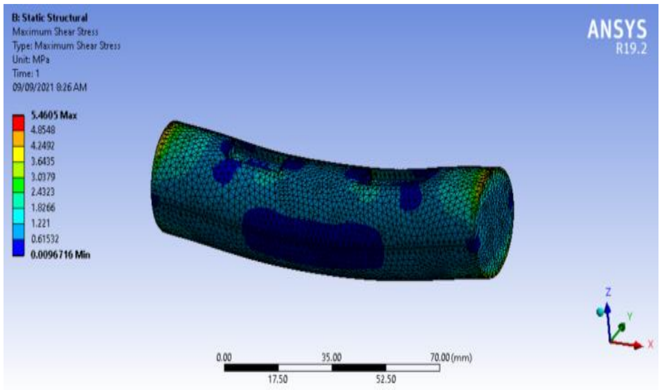


Fig. 9 Intermediate shaft analysis of shear stress when the mesh size is 1 mm

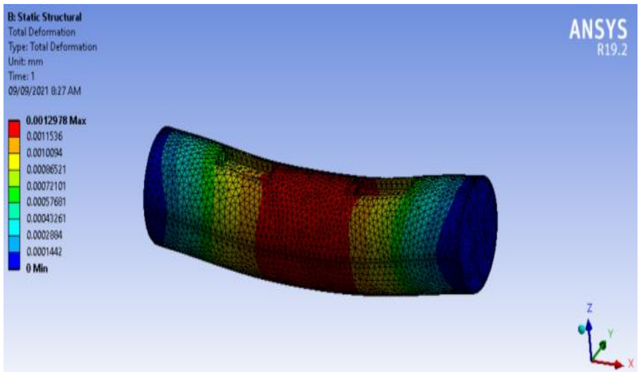


Fig. 10 Intermediate shaft analysis of deformation when the mesh size is 1 mm

Similarly, as presented in Figure 9, the maximum shear stress (5.4605 MPa) happens at the same place as a result of pulley weight and belt tensions. Additionally, the assessment implies that the ultimate shear strength of the shaft material is greater than that of the software analysis of maximum shear stress (250 MPa>>5.4605 MPa). From this result and along with Maximum Shear Stress Theory, an intermediate shaft does not fail under the applied load. Furthermore, in Figure 10, the total deformation is maximum (0.0012978 mm) at the middle part of the intermediate shaft, where there are belt tensions and pulley weights. The total distortion of the intermediate shaft is also in the safe range compared to material elongation.

The major reason for load differences on shafts is the pulley's rising diameter, which means when the diameter of the pulley rises for the same pulley material, its weight rises. As we have seen, the analysis results of deformation from shaft to shaft are decreased due to variations in the dimensions of shafts. The decrease in deformation from the screw shaft to the intermediate shaft is because of a decrease in the length of shafts, which means the length of the intermediate shaft is less than that of the screw shaft for similar materials.

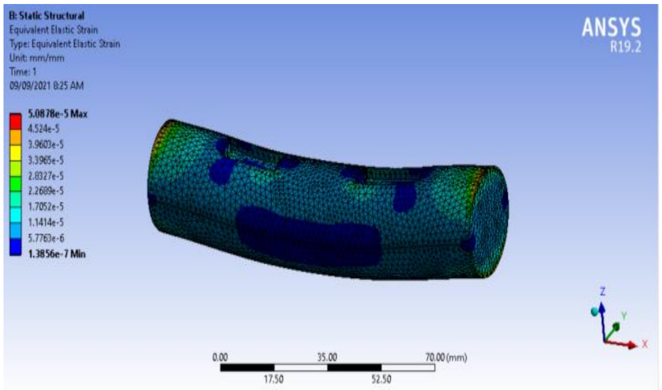


Fig. 11 Intermediate shaft analysis of equivalent elastic strain when the mesh size is 1 mm

4. Conclusion and Recommendation

4.1. Conclusion

The extraction machine was fabricated to extract oil from the processed seed. The prototype is driven by a 3kW 750 rpm electric motor by a V-belt system which liberators the power desired to the screw shaft on which the chamber is fixed. The chamber presses the processed seed along the screw shaft to extract the oil. The jatropha seed is fed into the chamber for processing within the hopper. The prototype was aimed to process about 120 kg/h of the jatropha seed for small-scale manufacture. The design was sectioned into the hopper and chamber, the stand support and the power delivery mechanisms. Performance assessment of the model displays that its efficiency is between the ranges of 92.59 to 98.04%, and the volume of extraction is the same for 3, 6, and 9 kg loading (120 kg/h).

4.2. Recommendation

The design and performance assessment of the prototyped jatropha seed oil extraction machine should be further improved and analyzed according to the findings during this study on the total performance assessments.

Moisture and heating influence on the machine, as well as seed, can be studied.

The impact of temperature on the oil and byproduct of the seed should be investigated.

The oil extraction machine was fabricated at WSU, whereas governmental incentive is very crucial to reduce environmental pollution and socio-economic impact by planting the jatropha seed as well as giving awareness to farmers about multi uses of the plant and supporting financially for mass production of the prototype and further investigation.

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