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Conceptual Design and Computer Aided Static Analysis of Frame and Plates of a Continuous Process Breadfruit De-Pulping Machine

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Abstract

The conceptual design, solid modeling, computer aided static analysis of frames and plates of a continuous process breadfruit (*Treculia africana Decne*) de-pulping machine is presented. The aim is to improve the method of breadfruit de-pulping in rural areas by creating a mechanism that de-pulps the seeds and to carry out a static analysis on the frame and plates. The conceptual design was gotten from mechanization of the traditional method of de-pulping and also from exiting literatures. The modeling was done using computer aided design software. The machine has an overall dimension of 2522mm × 540mm × 1198mm as its length, width and height respectively and weighs approximately 178kg as modeled. Static analysis/ Finite Element Analysis (FEA) were carried out on the frame and the plates of the machine using computer aided design simulation software. This is to ascertain the level of deformation and strength check on the plates and frame. The specific material of the component, load, torque and constraints were specified on the simulation environment before simulation. The material assigned to the frame and plates are mild steel. Von Mises failure criterion was used to examine the effects of the forces and torque on the plates and frames. The result showed that the stresses and the displacement are within the acceptable limit for the design. The results of finite element analysis (static analysis) and the deformation analysis on the frame and plates show von misses stress value ranging from 0.042-52.33 Mpa for the plates and 16.47 Mpa for the frame. The maximum deformation on the frame is 0.164 mm. It is recommend that frame and plates should be fabricated likewise the mechanical functional design, fabrication and testing of the machine. it will also eradicate the tedious nature involved in the traditional way of de-pulping and cleaning of the breadfruit seed.

Keywords

Breadfruit, Conceptual Design, Solid Modeling, De-pulping, Computer Aided Design, Finite Element Analysis, Static Analysis, Mild Steel

1. Introduction

Treculia Africana also known as African bread fruit is a tree species in the genus *Treculia* and belongs to the taxonomic family of *Mureccae*. In West Africa, individual breadfruit trees are found scattered throughout the southern rain forest zones. It is used as a food plant in Nigeria and some other countries of West Africa. It is popularly known as ukwa by the Igbo, afon in Yoruba, ize in Benin, izea in Ijaw and ediang in Efik [1]. The seeds may be eaten after boiling or frying and in many delicacies; including porridges which are commonly produced from the seed. The seed also produces weaning foods, breakfast cereals and beverages [2]. The crop is a rich source of high quality vegetable protein, oil and carbohydrates [3]. It also contains essential vitamins and minerals [4].

Solid modeling is a process of representation of solid parts of an object on a computer system with the aid of Computer Aided Design (CAD) software. Solid modeling as applied in engineering design helps to accelerate the design stages/steps, saves time, saves developmental cost and also boasts productivity. 3D solid models also help in product development and provides basis for design, dynamic simulation, Finite Element Analysis (FEA) and ease of manufacturing. Over the past decade, several new developments have taken place in the world of computer graphics. These include features-based, parametric solid modeling and assembly modeling [5]. Modeling is the process of producing a model; a model is a representation of the construction and working of some system of interest [6]. Solid modeling as a complete geometric data representation of an object as it enables points in space to be classified relative to the object, if it is inside, outside, or on the object [7]. According to [8], a solid model is an unambiguous computer representation of a physical solid object. Solid modeling is the most advanced method of geometric modeling in three dimensions. Solid modeling is the representation of the solid parts of the object on the computer. The typical geometric model is made up of wire frames that show the object in the form of wires. This wire frame structure can be two dimensional (2D) or three dimensional (3D). Geometric modeling was developed next, which is a mathematical model that captures the three-dimensional geometry of the physical object [5]. In recent decades, compliant mechanisms (CM) have become an important area in mechanical science which is rapidly developing due to dramatic improvement of technology, need for high precision, small scale and low final cost [9].

Authors of [10] used Pro/e wildfire 2.0, Altair hyper mesh and Optistruct 8.0 solver software's to run the solid modeling and finite element analysis of a crane boom. They also stated that the software's enabled them to get the variation of stress and displacement in the various parts of the crane boom and possible actions taken to avoid the high stress level and displacement. [11] worked on computer aided structural analysis of axle tilting effect on tractor front axle support. They used creo elements in modeling of the axle support. The structural analysis of the component was done with the worst load case using Pro -Mechanica. Computer aided design for single phase induction motors based on a new geometrical approach was done by [12]. They concluded that minimum iron volume was used when compared with existing motors and the output of the new design was better off. [13,14] produced Solid models for two different tricycles and Simulated it using Solid works flow xpress, Mathematical models were applied to compare the rate of fuel consumption and gas emission between the simulated models. Authors of [15] designed a computer program for the design of a package for single tooth per starter pole switched reluctance motor. Results from the program gave a clear indication of the effects of the design parameters on the motor performance. This enabled them to make a reasonable estimation of the design parameters. Authors of [16] used Autodesk Inventor stress simulation module to analyze and run a comparative evaluation on stresses resident on cast iron and aluminum alloy motorcycle hub under critical load environments. Findings made confirmed that the aluminum alloy hub have less weight than the cast iron hub which helps to reduce the inertia (the work done to move or stop the motorcycle hub). Further, the findings showed that the aluminum alloy hub has a good weight to strength ratio when compared to cast iron. The study therefore concluded that, regardless of the material cost and manufacturing cost of both hubs, the aluminum alloy hubs are better alternatives to the cast iron hubs. [17] used ANSYS as the simulation software to analyze helmet with different conditions such as bottom fixed-load on top surface, bottom fixed–load on top line, side fixed–load on opposite surface, side fixed–load on opposite line and dynamic analysis. The maximum force of 19.5 kN was applied on the helmet to study the model in static and dynamic conditions. The simulation was carried out for the static condition for the parameters like total deformation, strain energy, von Mises stress for different cases. Authors of [18] 2015 used E-Simulator (E-Simulator is a parallel FE analysis software package developed to accurately simulate structural behavior up to collapse by using a fine mesh of solid elements) to analyze a full-scale four-story steel frame structure, subjected to consecutive 60% and 100% excitations. [19] Designed a frame with conventional CAD design practices and then analyzed it statically with FEA Software. The structural loads considered during analysis were the actual loading cases. The analysis was carried out to determine the induced stresses and the deflections at various locations on proposed frame and further analytical calculations were done to verify the simulation results. [20] Designed, Analyzed and Fabricated a Quadcopter. Finite element analysis was done on the frame so as to sustain the loads generated in the vehicle and it was concluded that small deformation occurred on the center plates are safe and within the limit.

CAD modeling software will be used in modeling of a continuous breadfruit de-pulping machine. This will help to appreciate the visual appearance of the machine, working principle and the functionality of the components parts of the machine.

The purpose of the study is to elaborate the importance of CAD software in engineering designs and its uses i.e. in modeling, designing, evaluation, optimization and simulation.

The significance of this work is to eliminate the time wasted in conventional machine drawing and building, save lots of energy and also eliminate the cost of rebuilding a machine when functionality and reliability in performance are in doubt. Secondly, designing and development of the machine will aid in eradicating the dirty, slow and tedious method (traditional method) of de-pulping/cleaning of T. Africana. Lastly, the study will serve as a guide/reference material for future research and product development work on the machine.

1.1. Traditional Method of De-Pulping and Review of Existing Breadfruit De-Pulping Machines Traditional Method of De-Pulping

Presently, in some areas de-pulping of the breadfruit is done manually and the method is sluggish, muddy and monotonous, requiring significant quantity of water. The method involves cutting the fruit head into lesser pieces and allowing it to decompose over 3-9 days. The spongy fiber is separated from the hardcore or stone, and then the mixture of the seed and the fiber is placed in a basket and inserted in pool of water where the fiber is pulped without damaging the seeds.

Review of Existing De-Pulping Machine

Bread fruit de-pulping machine is a mechanical device designed for cleaning of bread fruit seeds. Author of [21] designed a machine for this purpose; the machine is similar to a batch agitator. The machine is being driven by 1.5KW electric motor and has a recommended shaft speed of 137rev/min. The machine consists of 8 major components, namely the motor, hopper, speed reduction unit, screw conveyor, shearing plate, screw housing unit, paddle and pumping/washing system. The details and working principle of the machine is seen in the works of [21].

In order to overcome the problem of high water consumption and noise generated in the works of [21], as well as increase the processing capacity. Authors of [3] developed a continuous flow bread fruit de-pulping machine. The machine consists essentially of four (4) main components namely the hopper/de-pulping chamber, connector pipe, separator and power system. The details of the work and working principle are seen in the works of [3].

1.2. Conceptual Design and Working Principle

The conceptual design of the proposed breadfruit de-pulping machine is conceived and modeled using Autodesk Inventor software, the machine is a continuous process method in de-pulping. It is made up of two different sub systems, the two sub system are assembled together to form a complete system. The full assembly of the machine is shown in figure 1.

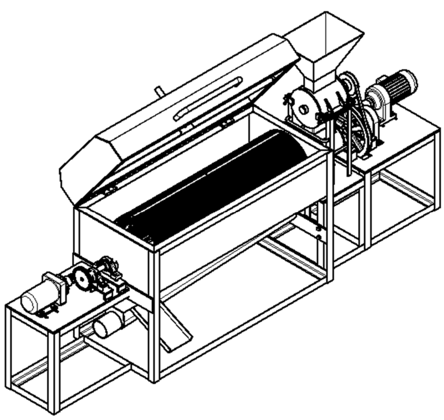

Figure 1. *Isometric view of the continuous breadfruit de-pulping machine.*

The two systems that make up the machine are;

- Digestion unit
- De-pulping/Separation unit

Digestion Unit:

The main purpose of the digestion chamber/unit is to break the pulp into smaller pieces for effective de-pulping and cleaning.

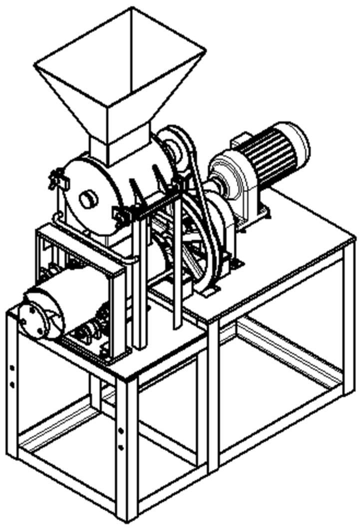

Figure 2. *Isometric view of the digestion unit.*

The pulp is loaded into the hopper and it falls under gravity through the outlet channel to the digestion chamber. In the digestion chamber, it is further reduced into smaller bits/pieces by the rotating spike which is driven by an electric motor. The digested piece(s) in the digestion chamber also fall under gravity through the outlet channel to the screw conveyor. The conveyor shaft transfers the resulting pulp to the separation chamber.

Separation/De-Pulping Unit

The separation chamber is shown in the figure 3. The main function of the separation chamber is to separate and clean the breadfruit seed from the slimy fiber. The major components in this unit are the brush-shaft assembly, wire mesh, water sprinkler and the electric motor.

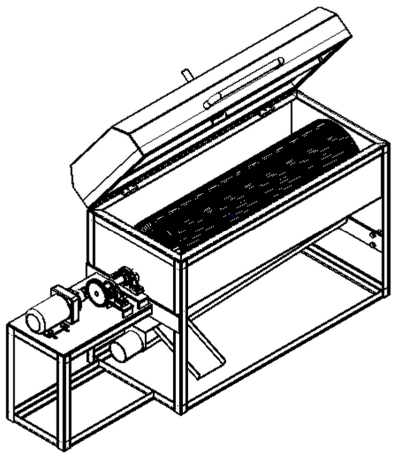

Figure 3. *Isometric view of the de-pulping/separating chamber.*

The system is designed in such a way that the brush-shaft assembly and the wire mesh rotate in opposite directions. As the disintegrated/digested pulp enters the separating chamber, the brushes tend to press them on the wire mesh and thus force the slimy fermented substance out of the system while the clean seed stays behind. The brushes are also arranged in a spiral form (i.e. inclined at an angle). This arrangement conveys the seed to the exit section and also reduces resident time of the seeds in the chamber. Thus, for better performance of the machine, the brushes could be adjusted to suit a specific purpose. More so, this unit is designed to have a sprinkler system located at the top of the cover, this introduces water into the chamber.

1.3. Distortion Energy Theory (Hencky and Von Mises Theory)

Distortion energy theory is the best theory to use in predicting failure for ductile materials [22]. According to this theory, the failure or yielding occurs at a point in a member when the distortion strain energy per unit volume in the actual case reaches the limiting distortion energy or the distortion energy in a simple tension case (uniaxial stress system) at the time of failure. Mathematically, the Von Mises equation can be derived from strain energy density function.

$$U_o = U_v + U_D = \frac{\sigma_1 + \sigma_2 + \sigma_3}{18K} + \frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3+\sigma_1)^2}{12G} \quad (1)$$

But

$$K = \frac{E}{3(1-2v)} \quad (2)$$

$$G = \frac{E}{2(1+v)} \quad (3)$$

At yield under uniaxial stress, $\sigma_1 = Y, \sigma_2 = \sigma_3 = 0$

From equation 1,

$$U_D = \frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3+\sigma_1)^2}{12G} = \frac{2Y^2}{12G} = \frac{Y^2}{6G} \quad (4)$$

$$J_2 = -\frac{1}{6}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2] \quad (5)$$

$$U_D = \frac{1}{2G}|J_2| \quad (6)$$

$$J_2 = I_2 - \frac{1}{3}I_1^2 \quad (7)$$

Where:

$$I_2 = \sigma_1.\sigma_2 + \sigma_2.\sigma_3 + \sigma_3.\sigma_1 = 0 \quad (8)$$

$$I_1 = \sigma_1 + \sigma_2 + \sigma_3 = \sigma = Y \quad (9)$$

$$\frac{1}{6}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2] - \frac{1}{3}Y^2 = 0 \quad (10)$$

$$Y = \sqrt{\frac{1}{2}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2]} \quad (11)$$

Where:

$U_o = Total\ strain\ energy\ density$
$U_v = Volumetric\ change$
$U_D = Change\ due\ to\ distortion$
$U_o = Total\ strain\ energy\ density$
$K = Bulk\ modulus$
$G = Shear\ modulus$
$I = Stress\ invariants$
$J = Deviatoric\ stress\ invariants$
$Y = Yeild\ limit$
$S_y = Yeild\ strenght\ of\ the\ material$

Thus for failure of ductile material equation 11 must be greater or equal to the yield strength of the material. Mathematically,

$$Y = \sqrt{\frac{1}{2}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2]} \geq S_y \quad (12)$$

2. Frame and Plate Analysis

2.1. Frame

The design of machine frames and structures is largely an art [23]. Frame design involves the stability, strength and rigidity of members in a structure. The basic objective in frame analysis and design is to produce a structure capable of resisting all applied loads without failure during its intended life. The primary purpose of a structure is to transmit or support loads.

The frame analysis was performed using computer aided design simulation software. The frame parts were modeled and assembled before being exported to the frame simulation environment to check the strength and the level of deformation on the frame. The values of loads used for the analysis were obtained from properties tab of the CAD software and is as summarized in table 1, this values are the sum of individual components of the machine resting on different sections of the machine. The weights were assumed to be evenly distributed on the frame by sections. Fixed constraints were used in constraining the base of the frame to ensure stability before performing the frame analysis simulation. Table 2 shows the material properties for the frame. The simulation solves equation 11 (it solves the Von Mises stress on the frame)

Table 1. *Frame weight distribution table.*

S/N	Section	Mass (kg)	Weight (N)
1	Digestion Unit	77.663	776.63
2	De-pulping/Separation unit	98.824	988.24

Table 2. *Material property for the frame.*

Name	Steel, Mild	
General	Mass Density	7.860 g/cm^3
	Yield Strength	207.000 MPa
	Ultimate Tensile Strength	345.000 MPa
Stress	Young's Modulus	220.000 GPa
	Poisson's Ratio	0.275
Stress Thermal	Expansion Coefficient	0.0000120 /c
	Thermal Conductivity	56.000 W/(m K)
	Specific Heat	0.460 J/(kg K)
Part Name	ISO L38x38x4	

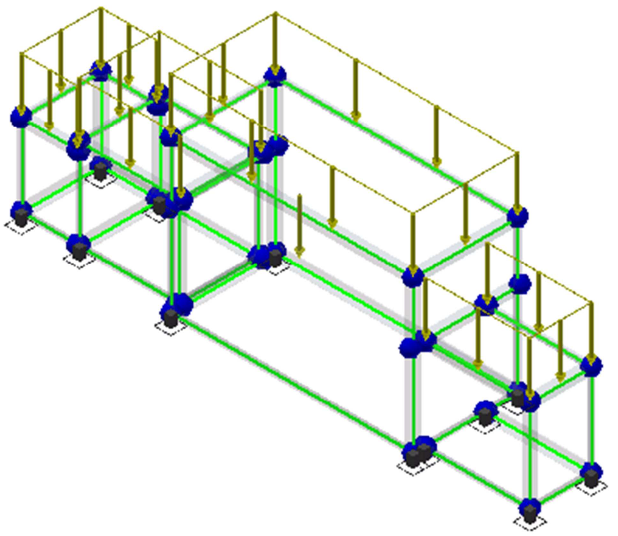

Figure 4. *Weight distribution on the frame.*

2.2. Plates

Static analyses were performed on the plates. The forces or loads used in the simulation were gotten from the properties tab of the modeling software and are assumed to be acting at the center of the plate. Fix constraint was used in fixing the edges of the plates. This is to create / represent the actual scenario of the plates. Gravity magnitude and direction was also specified, this allows the self-weight of the plates to act on them during simulation. Table 3 shows the force, torque used in simulating / analyzing the plates. The toque used is the driving torque of the electric motor and it is assumed to be acting on the motor adjustment slots on the plates. The forces were gotten from adding the individual forces of the machine components on the specific plate. Digestion chamber plate 1 is 10mm thick while digestion chamber plate 2 and de-pulping chamber plate is 8mm thick. The plate's material is mild steel with the yield strength of about 207 Mpa. The sole purpose of the simulation is to run a static strength check on the plates and determine whether it can withstand the loads and torques acting on them.

Table 3. *Loads on the plates.*

Plates	Force (N)	Torque (Nm)	Material
Digestion chamber plate 1	279.75	-	Mild steel
Digestion chamber plate 2	130	190.986	Mild steel
De-pulping chamber plate	130	190.986	Mild steel

3. Result and Discussion

Table 4. *Mechanical properties of the frame.*

Moment of Inertia (I_x)	44729.779 mm^4
Moment of Inertia (I_y)	44729.779 mm^4
Torsional Rigidity Modulus (J)	1828.972 mm^4
Section Modulus (W_x)	1552.907 mm^3
Section Modulus (W_y)	1552.907 mm^3
Torsional Section Modulus (W_z)	289.500 mm^3
Reduced Shear Area (A_x)	111.482 mm^2
Reduced Shear Area (A_y)	111.482 mm^2

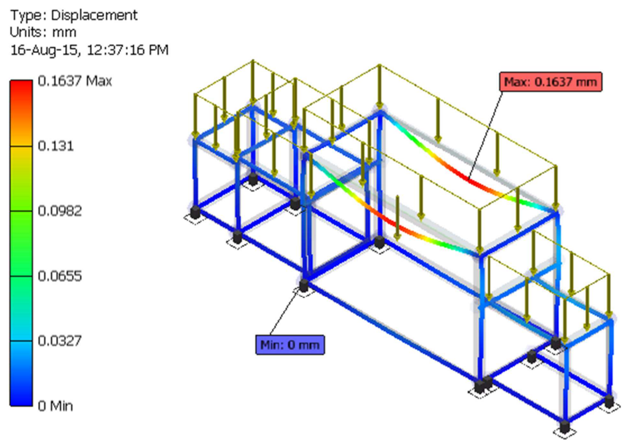

Figure 5. *Frame analysis displacement diagram.*

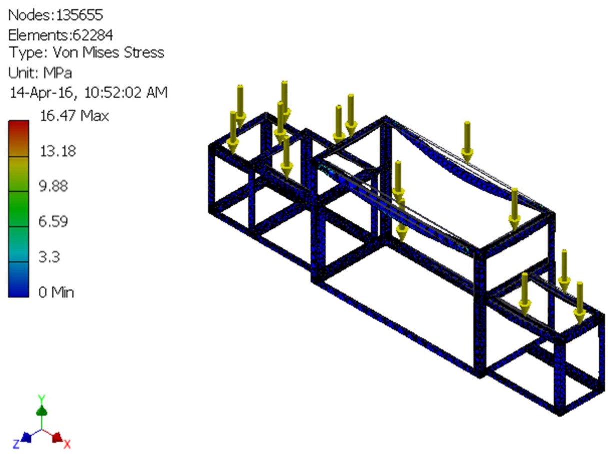

Figure 6. *Von Mises Stress diagram for the frame.*

Table 5. *Frame analysis Result.*

Name		Minimum	Maximum
Displacement		0.000mm	0.164mm
	Fx	-104.619 N	104.688 N
Force	Fy	-68.505 N	98.774 N
	Fz	-46.480 N	249.180 N
	Mx	-6889.765 N mm	16844.802 N mm
Moments	My	-16840.766 N mm	14294.505 N mm
	Mz	-175.475 N mm	70.803 N mm
	Smax	-0.556 MPa	9.052 MPa
	Smin	-13.430 MPa	0.016 MPa
	Smax(Mx)	0.000 MPa	4.437 MPa
Normal Stress	Smin(Mx)	-10.847 MPa	0.000 MPa
	Smax(My)	0.000 MPa	9.205 MPa
	Smin(My)	-10.845 MPa	-0.000 MPa
	Saxial	-0.809 MPa	0.151 MPa
Shear Stress	Tx	-0.939 MPa	0.938 MPa
	Ty	-0.886 MPa	0.614 MPa
Torsional Stresses	T	-0.245 MPa	0.606 MPa

The results for the frame are summarized in tables 4, 5, figure 5 and 6. The result shows the maximum and minimum values of displacement, forces, moments, normal stress, shear stress and torsional stress as shown in table 5. The maximum displacement is seen on the long horizontal frame member in figure 5. The red colour on the colour bar in figure 5 symbolizes area of maximum deformation while the blue colour on the bar signifies area of minimum deformation. The maximum deformation is infinitesimal but is magnified for clarity. The result of the frame analysis is positive to design compliance. Figure 6 show the Von Misses stress result or distortion energy theory result. The maximum Von Misses stress from figure 6 is 16.47Mpa and it is less than the yield strength of the material as stated in table 2. Thus the frame members will not yield when subjected to the loads in service.

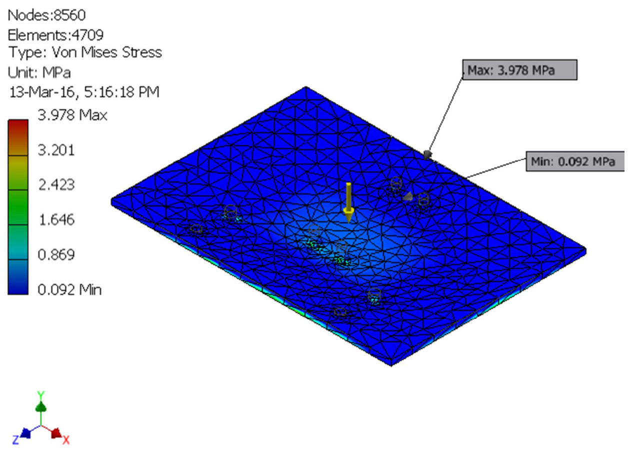

Figure 7. *Digestion chamber plate 1.*

The maximum von misses stress on figure 7 is 3.978Mpa while the minimum value is 0.092Mpa. The red colour on the colour bar signifies area of high stress concentration while the blue part signifies area of less stress concentration for figure 7, 8and 9. Von misses' failure criterion is used in evaluating the plate. According to the failure criterion, material will fail if the maximum value of von misses stress induced in the material is more than the yield strength of the material as shown in equation 12

The difference between the induced stress and the von misses stress is approximately 203Mpa from figure 7, in other words, the induced stress is approximately 52 times the yield strength.

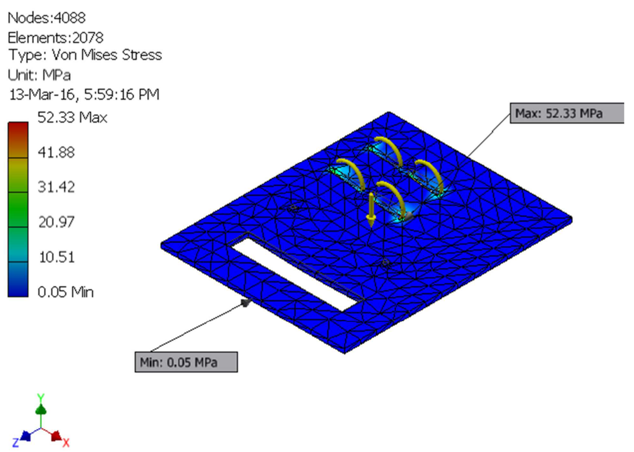

Figure 8. *Digestion chamber plate 2.*

Likewise for figure 8 and 9, the maximum von misses stress is 52.33 Mpa and 1.391Mpa respectively while the minimum value is 0.05Mpa and 0.042Mpa respectively. The difference between the induced stress and the von misses stress for figure 8 is approximately 155Mpa, in other words, the induced stress is approximately 4 times the yield strength.

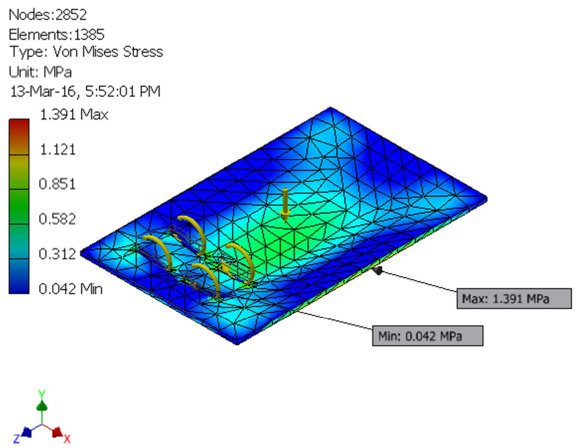

Figure 9. *De-pulping chamber plate.*

For figure 9, the difference between the induced stress and the von misses stress is approximately 206Mpa, in other words, the induced stress is approximately 149 times the yield strength. From the failure criterion in equation 12, the plates will not yield when subjected to the loads and torque in service.

4. Conclusion and Recommendation

The conceptual design and computer aided static analysis of frame and plates of a continuous process breadfruit de-pulping machine are presented. The modeling was done with CAD software. The machine has two main sub divisions fused into one to form a complete system. The division includes the digestion unit and the de-pulping unit. The main components of the digestion unit includes the inlet hopper, the spike shaft, conveyor, pulleys and electric motor while the de-pulping unit has the brushes, the wire mesh, electric motor, baffles, water sprinkler etc. as its components.

The result of the frame and plates after FEA reveals the suitability and stability of the materials and the dimensions for the intended purpose.

It is recommend that frame and plates should be fabricated likewise the mechanical functional design, fabrication and testing of the machine. This will serve as a reference to future research and development work on the machine.

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