The Finite Element Method (FEM) Approach to Determine Wire Loop Tooth and the Shaft of the Areca Nut Thresher Machine

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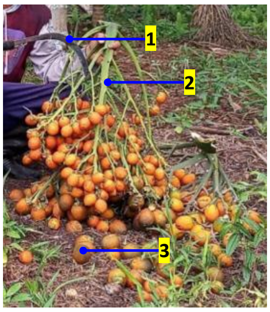
***Abstract*— An areca thresher machine will be developed to meet the need for appropriate technology in areca farmers. One of the critical points in this machine's design was related to the wire loop tooth and the shaft of the areca thresher machine used in the machine. As far as we know, studies related to the type of wire loop tooth material and the shaft of the areca thresher machine have not been carried out. Therefore, this paper investigates the effect of the type of wire loop tooth material and the shaft of the areca thresher machine on stress, strain, and displacement of the areca thresher shaft. The materials tested were 1023 carbon steel sheet (SS), ductile iron, and balsa wood. The method used in this research is a simulation using the finite element method (FEM) approach. The results show that the type of ductile iron material is the best material for the wire loop tooth and the shaft of the areca thresher machine considering the material's strength. Besides that, if you consider the mass and price of the wire loop tooth material and the shaft of the areca thresher machine, the balsa type material is the best.**

***Index Terms*— appropriate technology, betel nut, farmer, FEM, machinery**

I. Introduction

Betel nut is a type of palm plant that is cultivated massively in Indonesia. Areca fruit is harvested with fruit bunches using an "egrek" knife (Fig. 1). After the betel nut bunches are obtained, the betel nuts must be removed from the bunches manually and dried. This manual removal process is also called the threshing process. Betel nut threshing takes a long time if done manually. Not to mention, there are frequent abrasions on the hands of operators due to manual threshing. Therefore, it is important to develop a betel nut thresher machine.



1-knife harvester
2-bunches of areca nuts
3-areca fruits

Figure 1. Harvesting areca fruits [1]

Designing a machine takes agricultural products' characteristics to be processed so that the resulting machine can be efficient. Several researchers have studied the characteristics of betel nuts and their skin fibers [2-6]. Physical and mechanical properties in designing the thresher machines include the areca nut's dimensions, the hardness of the areca nut, and the amount of force to shed the areca nut. This is important so that the threshing machine cannot damage the agricultural products to be processed.

The design stage is needed to avoid failure in designing a machine [7-9]. One crucial design stage is converting an idea into an engineering drawing. It does not stop there; a simulation can also be done from an engineering drawing to predict the types of materials to be used, the mechanisms to be applied, and the machine's performance as a whole. This is conduct by Sitorus, et al.

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[10] in designing a knife from a Chinese spinach harvester. Other research, such as that of Lal [11], applies the finite element method (FEM) approach in modeling and estimating the speed-dependent bearing and coupling of a turbine generator.

Surprisingly, the simulation using the FEM approach has not been done to design a betel nut thresher, especially for the teeth and axle threshers. This is important to reduce the risk of failure when selecting the threshing machine's materials and construction. In that respect, we investigated the selection of suitable materials for wire loop teeth and the areca thresher machine's shaft through the finite element method (FEM) approach.

II. Methodology

A. *Material Properties*

The material properties used in this study are presented in Table I. In general, 1023 carbon steel (SS) is a material that is incorporated into the type of steel [12]. Ductile iron and balsa wood (*Ochroma pyramidale*) are materials incorporated in iron [13] and wood [14], respectively. The three types of material were chosen because they are very popular and easy to find in Indonesia.

TABLE I. Material Properties Used for Wire Loop Tooth and the Shaft of the Areca Thresher Machine

Parameter	1023 carbon steel (SS)	Ductile iron	Balsa	Unit
Elastic modulus	2.04×10^{11}	1.2×10^{11}	3.0×10^{9}	N/m^2
Poisson's ratio	0.29	0.31	0.29	N/A
Tensile strength	4.25×10^{8}	8.62×10^{8}	-	N/m^2
Yield strength	2.8×10^{8}	5.52×10^{8}	2.0×10^{7}	N/m^2
Thermal expansion coefficient	1.2×10^{-5}	1.1×10^{-5}	-	/K
Mass density	7858	7100	159.99	Kg/m^3
Hardening factor	0.85	-	-	N/A
Shear modulus	-	7.7×10^{10}	$3.\times10^{8}$	N/m^2
Thermal conductivity	-	75	0.05	W/(m·K)
Specific heat	-	450		J/(Kg·K)

The mass of the wire loop tooth and the shaft of the areca thresher machine of 1023 carbon steel (SS), ductile iron, and balsa is 2.12 kg, 1.91 kg, and 0.043 kg, respectively. The volume and surface area of the wire loop tooth and the shaft of the areca thresher machine of all types of materials used were 2.69×10^{-4} m^3, 5.29×10^{-2} m^2. The Center of mass wire loop tooth and the shaft of the areca thresher machine of all types of materials used are -25.35 mm on the x-axis, -0.33 mm on the y-axis, and 0.00 on the z-axis. Principle axes of inertia and principal moments inertia (kg.m^2) taken at the center of mass are presented in Table II.

TABLE II. The Inertia Moment of the Material

Parameter	**1023 carbon steel (SS)**	**Ductile iron**	**Balsa**	**Unit**
Px	3.01×10^{-4}	2.72×10^{-4}	6.13×10^{-6}	Kg·m^2
Py	4.93×10^{-2}	4.45×10^{-2}	1.01×10^{-3}	Kg·m^2
Pz	4.93×10^{-2}	4.45×10^{-2}	1.01×10^{-3}	Kg·m^2

B. *Experimental Procedure*

This study uses a simulation approach from the material being tested through the finite element method (FEM) approach. A 3D drawing of a wire loop tooth and the areca thresher machine's shaft was designed using a CAD application. The maximum load simulated in this study is 49.05 N per wire loop tooth thresher. This value is taken based on the approximate magnitude of the force required to shed betel nuts from their bunches. The flow chart of this research procedure is presented in Fig. 2.

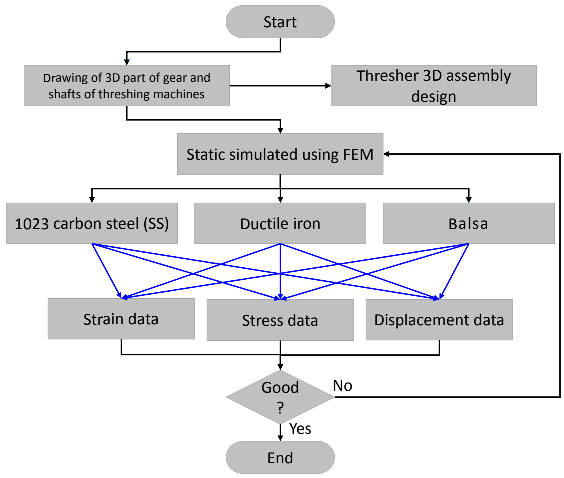


Figure 2. Research flow diagram

III. Results and Discussion

A. *The Design of the Areca Thresher*

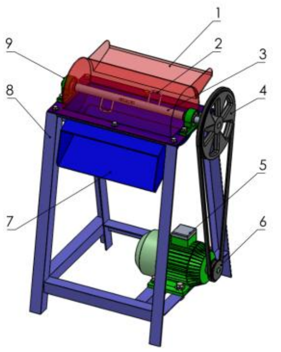
An areca thresher machine will be constructed with critical points on the teeth and thresher shaft (Fig. 3). The overall machine length, width, and height are 500 mm, 575.50 mm, and 860.53 mm, respectively. The thresher teeth have a diameter of 5 mm, and the thresher shaft is 25.4 mm in diameter. Thresher shafts are made multi-level as a holder for bearings measuring 20 mm. The power used based on the areca nut's mechanical characteristics, calculated using Equation 1, is 0.49 kW (0.65 Hp). The maximum rotating speed applied to the engine is 360 rpm. The pulleys on the motor shaft and threshing shaft are 50.8 mm and 203.2 mm, respectively.

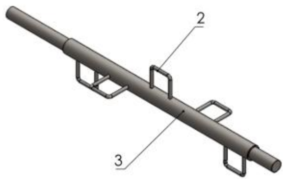
$$P = \left(F \cdot \frac{D}{2}\right) \times \left(\frac{2 \cdot \pi \cdot n}{60}\right) \tag{1}$$

where, P-power (watts), F-force needed to knock out betel nuts (N), D-diameter of thresher teeth (m), π-3.14, n-rotational speed in the shaft thresher (rpm).

B. *Material of 1023 Carbon Steel Sheet (SS)*

Analysis through the finite element method (FEM) approach of 1023 carbon steel sheet (SS) material is presented in Table III. In this material, the maximum stress parameter value through the von Mises approach is 623,000 N. This value is much lower at 99.78 than the yield strength of 1023 carbon steel sheet (SS) material. Also, maximum displacement and strain due to this loading are 0.001025 mm, 2.36×10^{-6}, respectively. This shows that this material is perfect for use in the design of the areca thresher. This is in line with the results of research by Chih-Chiang, et al. [15], which uses 1023 carbon steel as shaft systems in great five-axis turning-milling complex CNC machines.

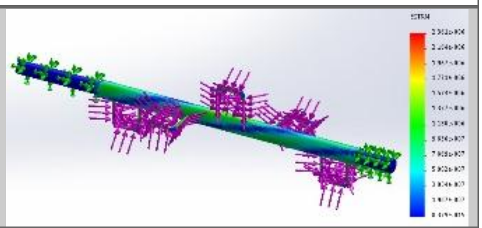
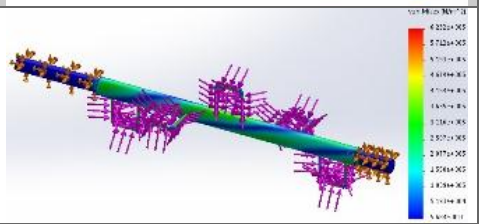
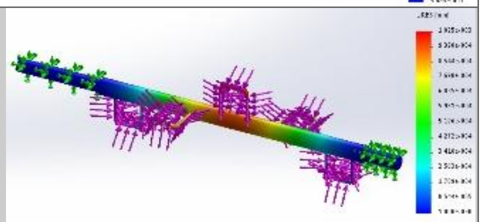




1-hopper; 2-wire loop tooth; 3-shaft; 4-pulley in thresher shaft; 5-electric motor; 6-pulley in electric motor shaft; 7-outer; 8-frame; 9-bearing

Figure 3. (a) full design (b) detail wire loop tooth and the shaft of the areca thresher machine

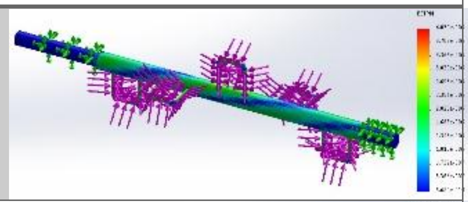
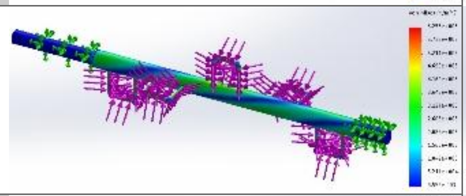
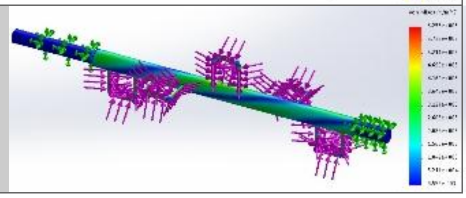
TABLE III. FEM SIMULATION ON 1023 CARBON STEEL SHEET (SS)

Parameters [Min - Max]	Result
Strain [8.38×10^{-15} – 2.36×10^{-6}]	
Stress (N/m^2) [5.68×10^{-3} – 6.23×10^{5}]	
Displacement (mm) [1.00×10^{-30} – 1.03×10^{-3}]	

C. Material of Ductile Iron

Analysis through the finite element method (FEM) approach of ductile Iron material is presented in Table IV. This material provides a maximum stress parameter value through the von Mises approach of 625,300 N. This value is still much lower at 99.89% of the Ductile Iron material's yield strength. Besides, the maximum displacement and strain that may occur due to this loading are 0.001748 mm, 4.039×10^{-6}, respectively. This shows that this material is also very well used in the design of the areca thresher machine. Also, this type of material was reported by Torshizian, et al. [16] can be used as a housing spline in 4WD passenger cars and as a crankshaft in the industry [17]. Zammit, et al. [18] also reported the use of ductile iron as gears.

TABLE IV. SIMULATED FEM ON DUCTILE IRON MATERIAL

Parameters [Min - Max]	Result
Strain [6.62×10^{-14} - 4.04×10^{-6}]	
Stress (N/m^2) [9.55×10^{-3} - 6.25×10^{5}]	
Displacement (mm) [1.00×10^{-30} - 1.75×10^{-3}]	

D. Material of Balsa

The analysis through the finite element method (FEM) approach of the Balsa wood type material is presented in Table V. This material provides a maximum stress parameter value through the von Mises approach of 623,200 N. This value is still much lower at 96.88% of the Balsa material's yield strength. Besides, the maximum displacement and strain that may occur due to this loading are 0.07006 mm, 1.613×10^{-4}, respectively. This shows that this material is also very well used in the design of the areca thresher machine. This type of material has also been used as the combined savonius-darrieus wind turbine blade for irrigation application [19]. Other studies such as Rocha, et al. [20] also use Balsa wood for small-scale wind turbines on the grounds of a very soft and light material, which provides lighter blades and facilitates the construction of profiles. Bramantya and Al Huda [21] also reported the use of balsa wood for wind turbines, a model related to axial distance between two rotors.

From the point of view of material strength, simulated material types are known to apply to the betel nut thresher's teeth and shafts. The best order based on the material's strength is ductile iron, 1023 carbon steel sheet (SS), and Balsa wood. However, if you consider the threshing machine's total weight, then selecting of the best materials in the order is balsa wood, ductile iron, 1023 carbon steel sheet (SS). In addition, if you consider the material price (Table VI) of the teeth and shaft of the areca thresher so that there is no over design, then the selection of the best materials is balsa wood, 1023 carbon steel sheet (SS), and ductile iron.

TABLE V. SIMULATED FEM ON DUCTILE IRON MATERIAL

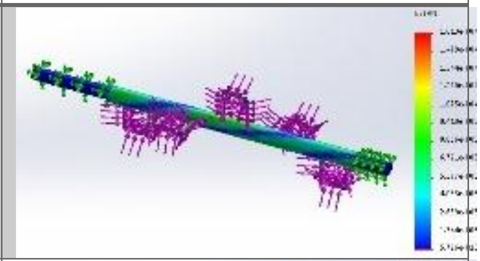
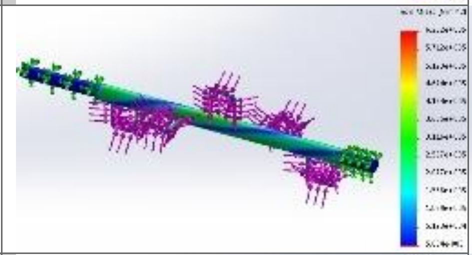
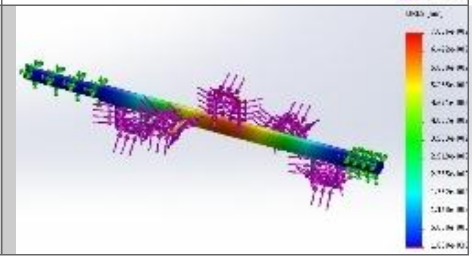
Parameters [Min - Max]	Result
Strain [5.73×10^{-13} - 1.61×10^{-4}]	
Stress (N/m^2) [5.68×10^{-3} - 6.23×10^{5}]	
Displacement (mm) [1.00×10^{-30} - 7.01×10^{-2}]	

TABLE VI. LIST OF THEIR PRICE (AS A NOVEMBER 2020)

Paremeter	1023 carbon steel (SS)	Ductile iron	Balsa	Unit
Mass	2,115.50	1,911.44	43.07	g
Unit price	0.66	3.68	12.13	USD/kg
Total price	1.39	7.03	0.52	USD

IV. CONCLUSION

Investigations of the material types for the wire loop tooth and the areca thresher machine's shaft have been carried out. The overall dimensions of the unit are 500 cm in length, 575.50 mm width, and 860.53 mm height. Thresher machines are allowed to operate on 0.49 kW (0.65 hp) of electricity.

The shaft material in the form of 1023 carbon steel sheet (SS), ductile iron, and balsa wood has been simulated using the finite element method (FEM). The maximum stress parameter value from 1023 carbon steel sheet (SS) material through the von Mises approach is 623,000 N. Maximum displacement and strain that may occur due to this loading are 0.001025 mm, 2.36×10^{-6}, respectively. Maximum stress parameter value from Ductile iron material through the von Mises approach is 625,000 N. Maximum displacement and strain that may occur due to this loading are 0.001748 mm, 4.039×10^{-6}, respectively. Maximum stress parameter value from Balsa wood type through the von Mises approach is 623,200 N. Maximum displacement and strain that may occur due to this loading are 0.07006 mm, 1.613×10^{-4}, respectively.

In general, the best material for wire loop tooth and the areca thresher machine's shaft is ductile iron from a material strength point of view and balsa material from a material weight point of view and a material price point of view. Aside from that, balsa material is the safest when considering the mass and price of the wire loop tooth material, as well as the shaft of the areca thresher unit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

AS, SR, AK conceptualized, implemented the research, and wrote the manuscript. DST, AS analyzed the data, and wrote the first draft. AS, RB, MQ, KS revised and gave advice to improve the research. All authors had approved the final version.

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