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Finite element analysis of fermentation frame design for cocoa beans using ASTM A36 material

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Abstract

Farmers in Berau Regency continue to conduct the cocoa bean fermentation process traditionally. In this traditional method, farmers use wooden boxes, which can lead to corrosion contamination due to the use of nails and other materials, potentially affecting the safety and quality of the resulting cocoa beans. The need for efficient fermentation technology has driven the development of a robust and safe frame design to support the cocoa bean fermentation process. This study aims to analyze the strength of the fermentation frame design made from ASTM A36 material using the finite element method (FEM) in Autodesk Inventor Professional 2024. The analysis includes stress distribution (Von Mises), displacement, and safety factor. The method begins with the frame design, followed by determining the frame dimensions and analyzing the frame using FEM under a load of 637 N. The simulation was performed to determine the maximum stress distribution, displacement value, and safety factor to ensure the design meets the required safety standards. The study results show a maximum Von Mises stress of 7.19443 MPa, a displacement of 0.0693914 mm, and a safety factor of 15. Based on these findings, the simulated frame design is technically categorized as safe from critical limits, and the cocoa bean fermentation device can operate effectively.

Keywords

Frame, FEA, ASTM A36, Static analysis, Autodesk inventor

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Introduction

Berau Regency is one of the farthest areas in East Kalimantan Province, which has a relatively extensive plantation sector. The five largest plantation commodities in Berau Regency are oil palm, copra, rubber, cocoa, and pepper (according to the 2022 statistics from the Berau Plantation Office) [1]. It is recorded that the cocoa bean production in Berau Regency amounts to 600,871 kg, with a total area of 1,003.80 hectares, and there are 872 cocoa farmers in the region according to the 2022 data [2]. The cocoa bean fermentation process in Berau Regency is still carried out traditionally. This method involves the use of wooden boxes, which pose a risk of corrosion contamination due to the nails used. This condition can affect the safety and quality of the cocoa beans produced. Therefore, technological innovation in the form of a cocoa fermentation machine becomes an important solution to improve the quality and efficiency of fermentation in a safer manner.

The development of technology in cocoa bean fermentation machines is a key solution to enhance the quality and efficiency of the fermentation process. With the introduction of this fermentation machine, it is expected that the process, which was previously done traditionally, can be optimized. The design of the cocoa bean fermentation machine aims to meet the need for effective fermentation during the post-harvest process carried out by farmers. The frame is the most crucial part of this design process because it will bear the loads on the machine, including both vibrations and static loads that occur during the fermentation process [3]. Manual testing of the frame's strength requires significant time and cost. Therefore, the use of more efficient methods, such as computer-based simulations, becomes essential to analyze the frame's strength more effectively [4]. The analysis is conducted using a computational system based on the Finite Element Analysis (FEA) method. This method can address various issues in complex structures in solid mechanics, generating data such as stress, strain, and deflection. One of the advantages of FEA is its ability to save time and cost. This method allows evaluation to be carried out before the creation of a physical prototype, with the help of software such as Autodesk Inventor [5].

Structural strength testing of machines using a simulation approach based on the Finite Element Analysis (FEA) method has become a widely used technique in various design and engineering fields. A study conducted by Alif et al. demonstrated that FEA can be used to analyze the maximum stress and load distribution on the frame of a press bearing machine with a high level of accuracy. The results of this study reveal that the FEA method can reduce the need for physical testing, which typically requires significant time and cost [6]. In addition, a study conducted by Firmansah showed that the application of FEA on the frame of a bamboo cutting machine can help detect potential deformation and damage before the manufacturing process. In the study, the simulation model was able to predict critical points that required reinforcement in the structure, thus enhancing the reliability and service life of the components [7][8].

This study aims to design and optimally analyze the strength of the cocoa bean fermentation machine frame using the finite element method. In the static load analysis, the data obtained includes the distribution of stress based on von Mises stress, displacement, and the factor of safety. The rationale behind conducting this research includes improving the productivity of cocoa bean fermentation processing at the farmer level, reducing dependence on manual labor, producing cocoa beans that are safe from contamination, using energy efficiently, and providing simple technology for cocoa farmers.

Method

Identification of variables

In this study, the authors define the variables as follows :

1. Description of Independent Variables.

   The independent variable determined in this study aims to assess the effect of material type on the strength of the machine frame. The independent variable in this study is ASTM A-36 with a load of 637 Newtons. ASTM A36 is a low-carbon steel known for its good strength, which can be shaped through machining processes, welded, galvanized, or coated to enhance its resistance to corrosion [9].

Table 1. Research Variables

No	Variable	Thickness
1	Angle Steel ASTM A36	5 mm

Table 2. Tensile Requirement ASTM A36 [10]

Tensile strength, [MPa]	**[400 – 550]**
Yield point, [MPa]	[250]
Elongation in 8 in. [200 mm], min, %	20
Elongation in 5 in. [50 mm], min, %	23

2. Description of Controlled Variables

   The controlled variable in this study is the loading on the cocoa bean fermentation machine frame, which is 637 N (65 Kg), using the Autodesk Inventor Professional 2024 software for simulation. Details of the components used for calculation purposes are presented in Table 3.

Table 3. Weight of Cocoa Fermentation Equipment Components

No	Component	Weight (Kg)
1	Cocoa Beans	40
2	fermentation box	20,5
3	Shaft	1,8
4	Flange	0,9
5	Nut and Bolt	0,5
6	Bearing	1.2
		64,9

3. Description of Dependent Variables

   The dependent variables in this study are the factors that affect the strength of the frame in the finite element method simulation, which include Stress Analysis, Displacement, and Safety Factor.

Cocoa Fermentation Frame Design

This study uses static load simulation with Autodesk Inventor Professional 2024 software. The experimental method with Autodesk Inventor Professional 2024 software is capable of analyzing the characteristics of a model [11]. The design of the cocoa fermentation machine is shown in Figure 1.

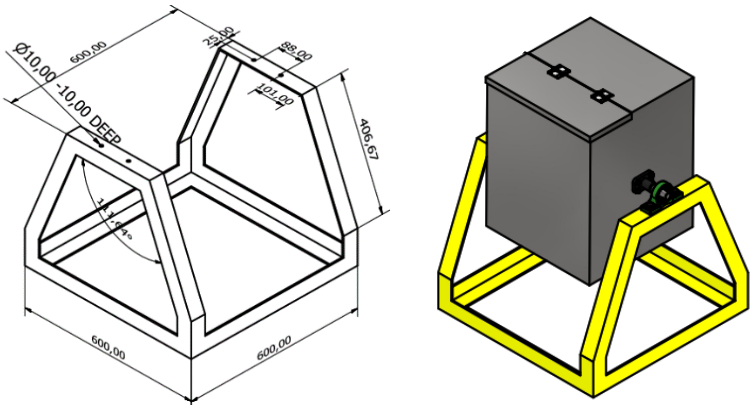

Figure 1. Design of the Cocoa Fermentation Machine

Next is the meshing stage. Meshing is the process of dividing the shape of an object into smaller components called meshes. The number of mesh elements is usually adjusted based on the requirements, particularly in areas with sharp changes that require finer division. On the other hand, for areas with more stable changes, the mesh division is done with a lower level of refinement [12]. At this stage, the component is divided into 17.294 elements and 36.518 nodes. The next step is to run the simulation program, which will generate outputs such as mass, Von Mises stress, safety factor, and deformation (displacement). This simulation process will highlight areas of the frame structure that experience stress based on the design that has been developed. The parameters analyzed to evaluate the stress on the frame are carried out using Autodesk Inventor Professional 2024 software, and the results can be seen in the Table 4.

Table 4. Stress Analysis Parameters

Variables	**Description**
Simulation Type	*Single point*
Gravitational Acceleration	9,81 m/s^2
Total load	637 N
Average element size	0,05
Minimum element size	0,2
Safety factor	*Yield-based*
Number of Nodes	36518
Number of Elements	17294

Results and Discussion

Table 5. Physical Properties of the Cocoa Bean Fermentation Machine Frame Material

Parameter	**Description**
Material	ASTM A36
Density	7,85 g/cm³
Mass	17,483 kg
Area	934929 mm^2
Volume	2227180 mm^3
Yield Strength	248,225 MPa
Ultimate Tensile Strength	399,9 MPa
Young's Modulus	199,959 GPa
Poisson's Ratio	0,3 ul
Shear Modulus	76,9073 GPa

Analysis of material properties is crucial for determining the parameters to be used in structural analysis. The physical properties of the material are presented in the Table 5 it shows the characteristics of ASTM A36 Steel, which has a density of 7.85 g/cm³. This density affects the calculation of the total mass of the cocoa bean fermentation machine frame structure, which is 17.483 kg.

Static analysis results

The simulation results show the Von Mises stress distribution on the machine frame structure, which was analyzed using Autodesk Inventor Professional 2024. Von Mises stress is used as the main parameter to assess the frame's ability to withstand the applied load [13]. As shown in Figure 2, the Von Mises stress distribution on the cocoa bean fermentation machine frame with the loading direction perpendicular to the Y-axis, with a Von Mises stress value of 7.194 MPa. The stress value is still below the yield strength of ASTM A36 material, which is 248.225 MPa, indicating that the frame structure is capable of withstanding the load effectively [14].

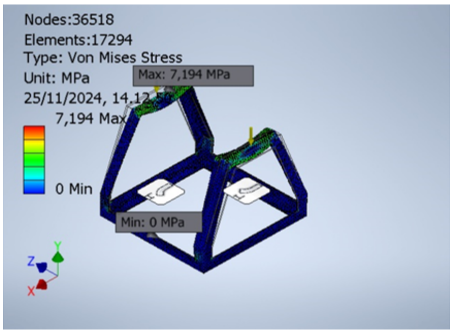

Figure 2. Von Mises Stress Distribution of the Cocoa Bean Fermentation Machine Frame Structure

Deformation or shape change is an important parameter for evaluating the material's ability to withstand the applied load. Deformation occurs as a result of the force or load applied to the material. The smaller the deformation value, the higher the material's strength. In Figure 3, it can be seen that the deformation value generated is 0.06939 mm, which indicates that the smaller the deformation, the stronger the material. Based on the simulation results, even though the component is subjected to a high load, the deformation remains small. However, if the frame structure cannot withstand the applied load, damage to the component may occur [15][16].

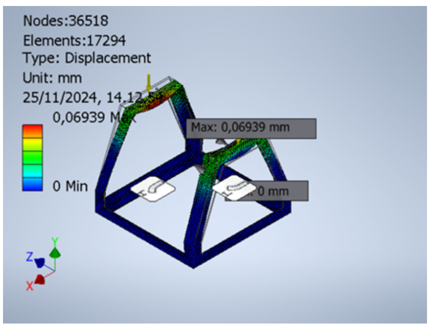

Figure 3. Deformation of the Cocoa Bean Fermentation Machine Frame Structure

As shown in Figure 4, the safety factor value is 15, indicating that this structure meets the requirements and can be considered safe. In general, the safety factor value in this study meets the criteria for withstanding static stress. Static stress is a type of stress that occurs when a load is applied at a low speed, without shock, and remains at a constant value. The stress that occurs under these conditions is referred to as static stress [17].

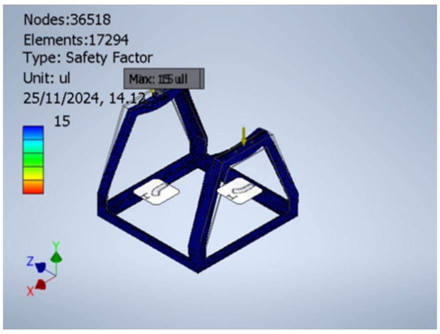

Figure 4. Safety Factor of the Cocoa Bean Fermentation Machine Frame Structure

Discussion

The results of this study show that the safety factor value for the cocoa bean fermentation machine frame structure meets the standards for withstanding static stress. Static stress is the stress that occurs when a load is applied gradually and remains constant. The achieved safety factor indicates that the frame structure has the strength to withstand the load without experiencing damage.

The simulation shows that even though the frame is subjected to a large load, the deformation remains minimal, indicating that the material has sufficient strength to withstand the pressure. The static stress, which is still below the material's yield strength, indicates that the frame design is safe. As shown in Table 5, the overall results of the simulation analysis using the finite element method on the cocoa bean fermentation machine frame.

Table 5. FEA Simulation Results for the Cocoa Bean Fermentation Machine Frame Material

Name	Minimum	Maximum
Von mises stress	8,34367 × 10^{-8} MPa	7,19443 MPa
Displacement	0 mm	0,0693914 mm
Safety factor	15 ul	15 ul

Conclusion

Based on the research findings, the frame structure design of the cocoa bean fermentation machine using ASTM A36 material has a mass of 17.483 kg. When subjected to a load of 637 N, the frame structure experiences a maximum Von Mises stress of 7.19443 MPa. Referring to the material's yield strength, this stress value is below the yield strength of ASTM A36, which is 248.225 MPa, categorizing it as safe. The frame structure undergoes a maximum deformation of 0.0693914 mm. Furthermore, the minimum safety factor obtained is 15, indicating that the frame structure design of the cocoa bean fermentation machine is safe to withstand both static and impact loads.

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