OPTIMIZATION OF PELTON TURBINE BUCKET DESIGN FROM COMPOSITE RESIN USING SOLIDWORKS

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Abstract. The Pelton turbine is a type of water turbine whose working principle utilizes the potential energy of water which is converted into kinetic energy through a nozzle. The fluid coming out of the nozzle push the bucket and rotates the Pelton turbine which ultimately produces electrical energy. Micro-hydro power plants that usually use Pelton turbines need to be developed to remote villages to meet electricity needs in Indonesia. Pelton turbine buckets, which are usually made of metal, are not only difficult to manufacture so they have to be specially ordered, but also easy to rust. Therefore, in this study, the bucket was made easier and simpler using an epoxy resin composite material reinforced with palm fiber. This makes it lighter and more corrosion resistant. The results of this study indicate that the epoxy composite fiber reinforced with 9% fiber volume has a higher tensile strength than the volume fraction 0%, 3%, 5%, 7%. The maximum tensile strength for 9% fiber content is 32.6054 N/mm^2. Then the tensile strength results are applied to the Pelton turbine bucket geometry with laboratory scale sizes that have been varied into 3 different size models in: bowl width (b), bowl height (h), and bowl height (h1). Based on solidworks simulation results all bucket models in this study have a factor of safety above the minimum limit of 6, therefore this composite can be used as a Pelton turbine bucket material. The first bucket version has a minimum factor of safety 6.656, the second bucket version has a minimum factor of safety 6.756, the third bucket version has a factor of safety 6.945.

Introduction

The Pelton turbine is one type of air turbine that works by utilizing the potential energy of air as air power, but after the fluid passes through the potential energy ns into kinetic energy that strikes the bucket, which causes the turbine wheel to rotate [1]. The rotation of the turbine shaft will be converted by a generator into electric power. The Pelton turbine has a concave blade, the pressure from the water flow turns into a force that provides torque to rotate the turbine wheel. Thus, the Pelton turbine bucket must be strong enough to withstand the forces that occur due to changes in the momentum of the water jet from the nozzle. This is a reference for utilizing river flow by turning it into a vortex flow [2].

In general, water turbines are divided into 2 categories, namely impulse turbines and reaction turbines. An impulse turbine is a turbine in which the rotation of the rotor is caused by the collision of the pressurized fluid shown in the rotor of the example of an impulse turbine, while a reaction turbine is a turbine in which the rotation of the rotor is caused by the pressure of the fluid coming out of the tip of the propeller through the nozzles. Power comes from the force of the water from the high pressure hitting the bucket, hence the name turbine impulse [3].

The need for energy is increasing day by day, the majority of power plants still use fossil fuels such as coal which has limited supply as happened in the Cilacap PLTU (Steam Power Plant) which is operated by the private sector, or PLTU Tanjung Jati B and PLTU Paiton which is operated by PLN, several times almost stopped operations due to lack of coal supply [4].

Utilization of water energy as a source of electricity is very beneficial, especially in areas that do not have electricity but have large water resources. as a matrix has a function as a binder, as a protector of the composite structure, gives Therefore, a Micro-Hydro Power Plant (MHP) was developed. MHP is a small-scale hydroelectric power plant that requires small power (10-150 kW), suitable for Pelton turbines [5]. The bucket is designed using a fiber composite material with an epoxy resin matrix material. Resin strength to the composite and acts as a medium for transferring the stress received by the composite and protects the fiber from abrasion and corrosion [6]. Mechanical properties of composite materials are influenced by the percentage of fiber content. When the natural fiber content is too low, there is a less or less significant increase in the mechanical properties of the composite material. However, as the fiber content increases, the strength also increases [7].

Method

The process flow in this research was carried out according to the flow chart shown in Fig.1.

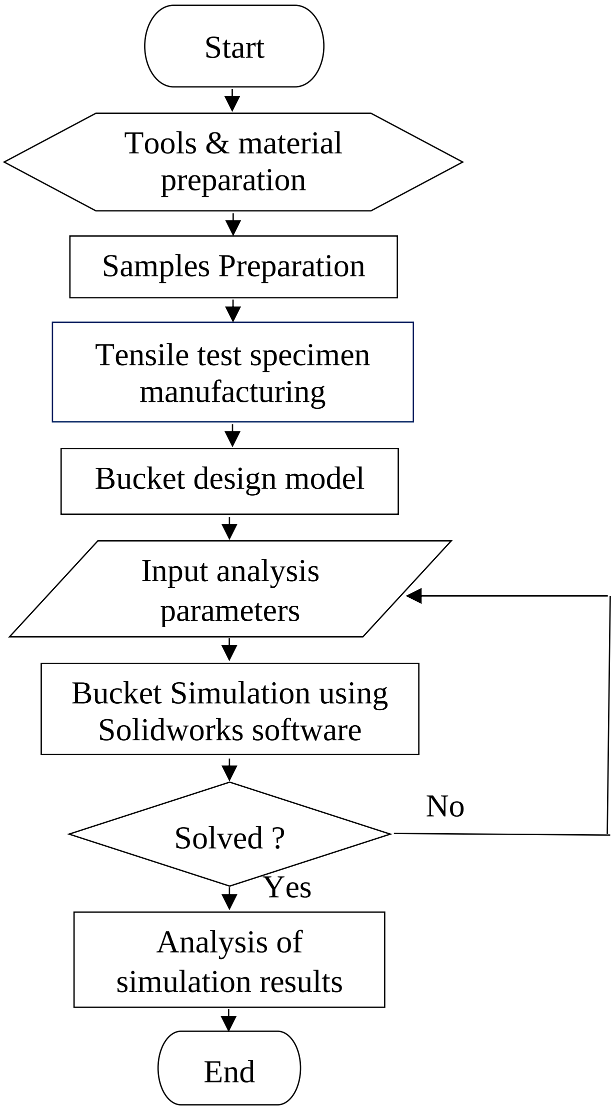
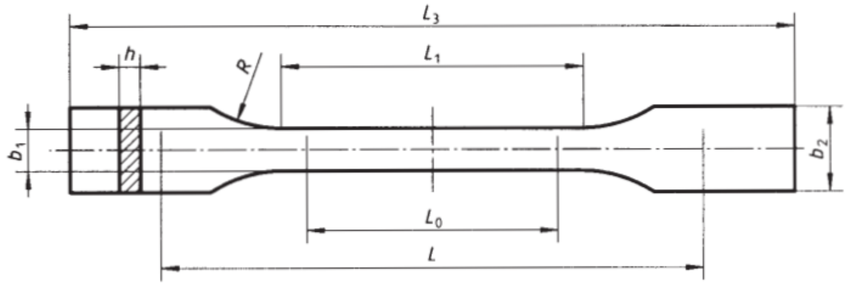


Fig. 1: Research flow process.

Equipment and Material Preparation. Equipment and materials related to research are prepared to support the research process. The tools and materials used in the research were as follows:

- Palm fiber (Arenga pinnata)
- Epoxy resin
- Hardener for epoxy resin
- Tensile test specimen mold with ISO 527 standard
- Precision weighing scale
- Tensile testing machine
- Laptop with solidworks software

Samples Preparation. The specimens tested in this research were shaped according to the ISO 527 standard [8]. The dimensions of the specimen are made according to Fig. 2 below.



Dimensions in millimetres

L_3	Overall length	$\geqslant 150$ 1)
L_1	Length of narrow parallel-sided portion	$60 \pm 0{,}5$
R	Radius	$\geqslant 60$ 2)
b_2	Width at ends	$20 \pm 0{,}2$
b_1	Width of narrow portion	$10 \pm 0{,}2$
h	Thickness	2 to 10
L_0	Gauge length (recommended for extensometers)	$50 \pm 0{,}5$
L	Initial distance between grips	115 ± 1

Fig. 2: Specimen dimension.

Composite Specimen Molding Process. Specimens were made of palm fiber material as reinforcement and epoxy resin as a matrix which was shaped according to ISO 527 standards. The specimens were made using a mold made from PLA (Polylactic Acid) which was made using 3D printing, the process of printing this composite specimen using the handy lay up method with elongated fibers.

The test carried out in this study was a tensile test, with the material being tested was a palm fiber composite as a reinforcement and an epoxy resin as a matrix. The load given to the specimen in principle provides a tensile force in the opposite direction which is attached to the chuck of the tensile test equipment which results in deformation and stress on the test specimen. [9].

The results of the tensile strength will be obtained by the following formula Eq. 1 [10].

$$\sigma = \frac{F}{(b \times d)} = \frac{F}{A0} \tag{1}$$

Description :
σ : Tensile strength (N/mm^2)
F : Maximum load (N)
b : Width (mm)
d : Thickness (mm)
A_0 : Sectional area (mm^2)

The summary of specification of test rig used for this study is presented in Table 1.

Table 1: Plant specifications

Spesification	Size
Power [Nm/s]	29.81
Debit [m^3/s]	0.00108
Absolute speed of jet [m/s]	9.59
Stab circle diameter/ PCD[mm]	179.5
Speed [rpm]	96

Result and Discussion

The simulation using the static method, in the simulation is carried out by giving a load which is calculated as follows Eq. 2.

$$F = \frac{P}{2\pi \, . \, R \, . \, n} = \frac{29.81 \text{ Nm/s}}{6.28 \, . \, 0.08975 \text{ m} \, .1.6 \text{ r/s}} = 33{,}055 \text{ N} \tag{2}$$

Description:
P : Voltage (Watt)
T : Torque (N.m)
ω : Angular velocity (rad/s)
R : Radius (meter)
F : Force (Newton)
π : 3,14 or 22/7
n : Rotation per second

Table 2: Composite tensile test results 9% content

Spesimen Number	Maximum Load [N]	Tensile Stength [N/mm^2]	Modulus of elasticity [N/mm^2]
1	1417.2	32.496	2315.9
2	1521.8	35.884	3289.4
3	1384.1	33.158	2791
4	1303.5	29.01	2492.6
5	1296.2	32.479	2371.8

Yield Strength. The yield strength of composite materials is difficult to see on the graph of the results, therefore in this study to determine the yield strength using the offset method

[10][11]. By drawing a straight line on the line when the specimen undergoes elastic deformation.

Formula to determine max load yield strength based on height per column in Microsoft excel The results of the max load yield strength based on height per column in Microsoft excel by the following formula Eq. 3.

$$\text{Max load for } \sigma_y = \text{Height total} \times 100\% / \text{Height per Coloumn} \tag{3}$$

Description :
Height per Coloumn : 14.4 : 24 Pixel : 0.63 cm

Table 3: Specimen yield strength

Specimen Number	Yield Strength [N/mm^2]
1	19.18
2	19.91
3	19.89
4	15.76
5	18.02

Average Yield Strength (σ_y). Then for the average value of the yield strength of the fiber composite material with this epoxy resin is 18.552 N/mm^2.

Specimen Failure Characteristics. All the specimens tested in this study had the same fracture characteristics, namely ductile fracture as shown in Figure 3. This was shown because there was a slight plastic deformation that occurred in the specimens.

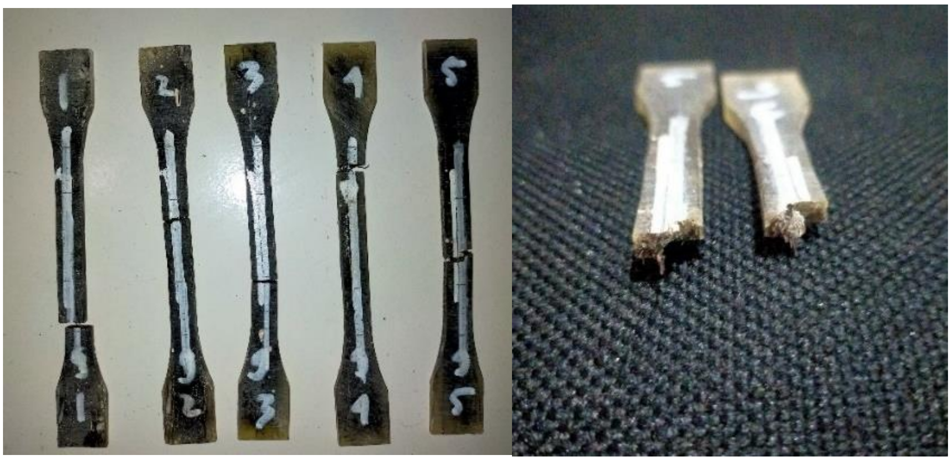


Fig. 3: Specimen failure content 9%

Bucket geometry. The force acting on the blade due to the jet of water from the nozzle changes direction after hitting the blade, the direction of the flow rate changes, resulting in a change in momentum, which is called as the impulse force [12]**.** The bucket size of Pelton turbine in this study is a laboratory scale size, with 3 of design models which were varied by on the side of the bowl width (b), bowl height (h), and bowl height (h1). By following the formula Eq. 4, Eq 5, and Eq 6 [13].

$$b = (2.5 \sim 3.2) \times d \ \{\text{for 3 version used } 3.0, 2.7, 3.2\} \quad (4)$$
$$h = (2.7 \sim 2.7) \times d \ \{\text{ for 3 version used } 2.7, 2.5, 2.1\} \quad (5)$$
$$h_1 = (0 \sim 0.35) \times d \ \{\text{ for 3 version used } 0.19, 0.25, 0.35\} \quad (6)$$

The nozzle diameter affects the overall Pelton turbine construction dimensions (especially the blade dimensions). To determine the optimal jet diameter (d) related to previous studies using the following formula Eq. 7 [14].

$$d = \sqrt{\frac{4 \times Q}{\pi \times C1}} \quad (7)$$

Description :

d : Optimum nozzle diameter (mm)

Q : Debit (m^3/s)

C_1 : Absolute speed of jet (m/s)

$$d = \sqrt{\frac{4 \times 0.00108\ m^3/s}{3.14 \times 9.59\ \mathrm{m/s}}}$$

$$d = \sqrt{\frac{0.00432\ m^3/s}{30.11\ \mathrm{m/s}}}$$

d = 0.01199 m

d = 11.99 mm =12 mm

Size bucket. The results of the measurements of the various models above, are concluded in the following Eq. 4, Eq. 5, and Eq.6. Results of determining the size of the bucket are shown in table 4 below.

Table 4: Bucket size models

Description	Model 1 [mm]	Model 2 [mm]	Model 3 [mm]
Bowl width (b)	35.9	32.4	38.4
Bowl height (h)	32.4	30	25.2
Bowl height (h1)	2.3	3	4.2

Geometry analysis. In the following table, the specification data for the Pelton V-1, V-2, and V-3 turbine buckets are attached for analysis. Solidworks has been widely used in analyzing and simulating various designs in various engineering applications. Solidworks is a software used to design a product, machine or tool [15]. The geometry applied to the analysis software already follows the actual calculation formula from the specified formula as shown in Fig 4.

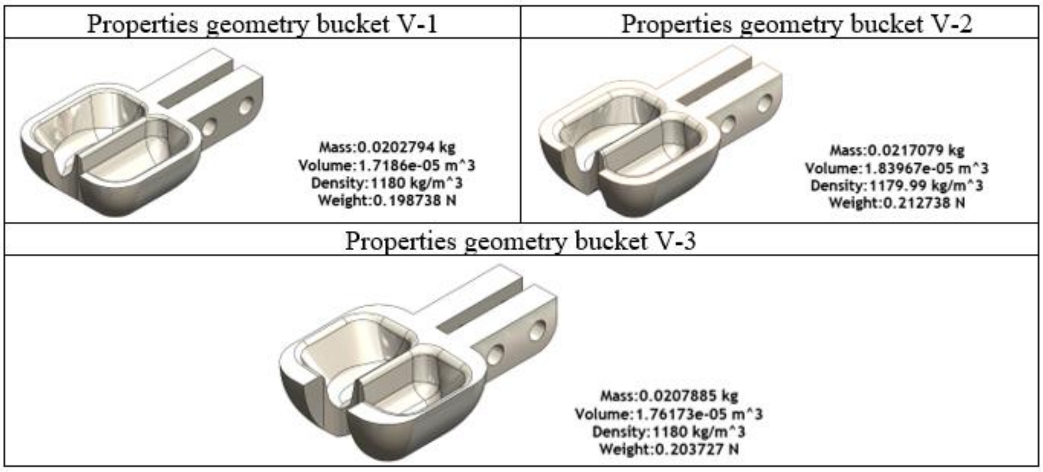


Fig. 4: Properties geometry bucket

Data Analysis. There are 3 data analysis generated from this research, as follows:

a. Tensile strength, yield strength, and Modulus of elasticity, of fiber-reinforced epoxy resin composite materials
b. Values of stress, strain, and deformation that occur in the Pelton turbine bucket from 3 different designs using the solidworks software.
c. Factor of safety of bucket.

Independent of Mesh. The validity of this study uses the Independent of mesh method in order to produce accurate results and streamline the calculation time in solidworks software [16]. Independent mesh or independent element division is done so that the final result is efficient in calculation time and accurate in results, because if the element size is large the calculation time is faster but the results are inaccurate, where as if the mesh size is too small, the calculation time is longer but the results are not accurate, so that the calculation time is not too long and the results are accurate, this method is carried out [17]**.** The analysis is to do an independent of mesh with the magnitude of the stress on the y-axis to the number of elements on the x-axis.

Independent of mesh as shown in Fig. 5 to see the difference if the mesh size changes then the number of elements and the results of the design simulation change.

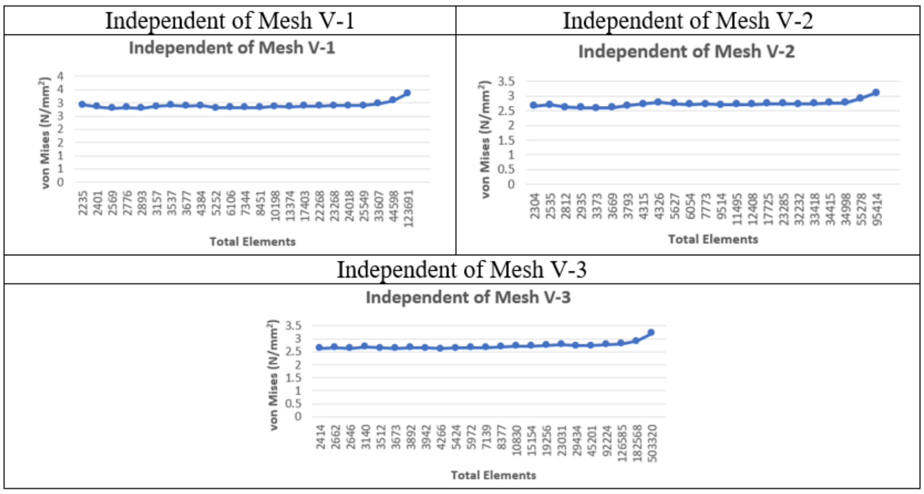


Fig. 5: Independent of Mesh

Based on Fig. 5 then the points that are in a stable condition are taken, which are listed in table 5 below.

Table 5: Bucket mesh size

Model Bucket	Mesh Size [mm]	Von Mises [N/mm^2]	Total Elements
1	2.8	2.8214175	7344
2	1.8	2.7417185	23285
3	2.8	2.6670575	7139

Deformation, stress, strain and factor of safety. Fig.6 shows the deformation results that occur in the simulation of the three buckets model with palm fiber reinforced epoxy resin composite material with palm fiber with 33.055 N.

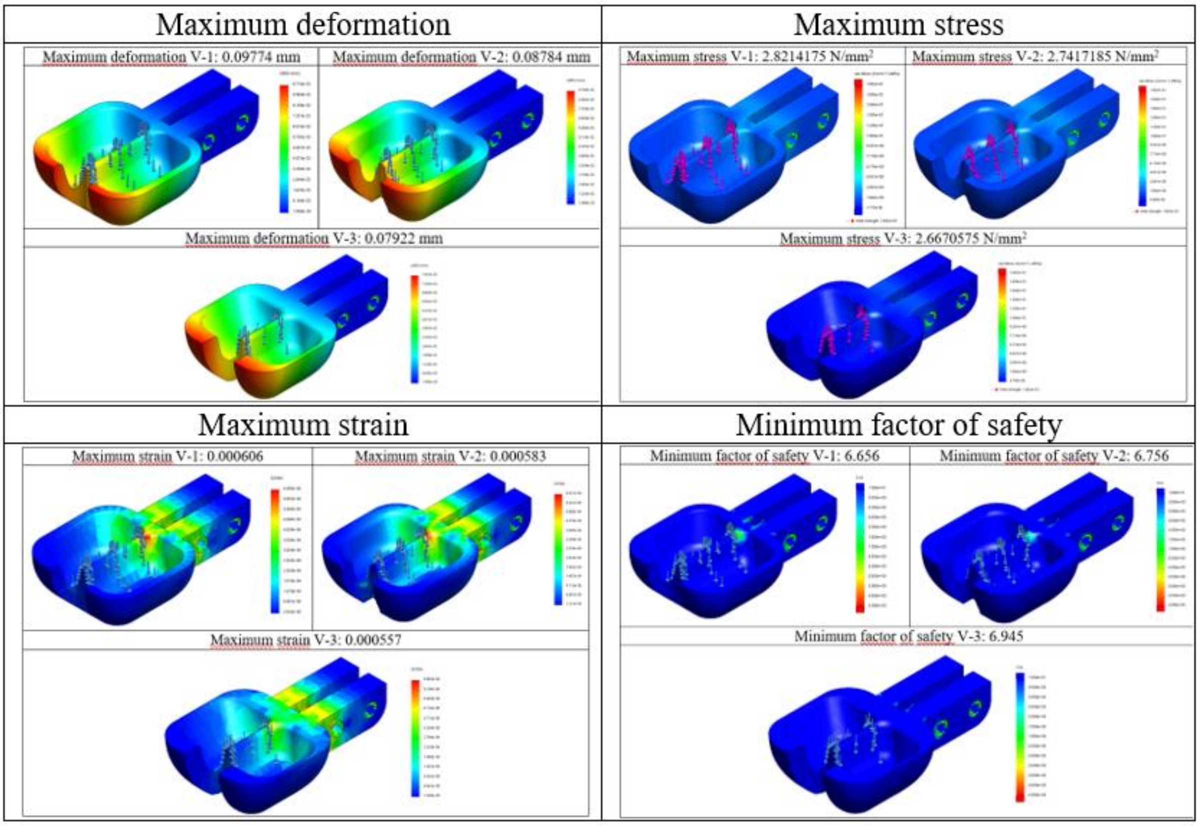


Fig. 6: Result simulation bucket

Based on the simulation results, the deformation of the model 3 of the bucket, experienced the least deformation. because it is thicker than the other models.

The safety factor is one of the important parameters to determine whether a construction is safe or not [18]. Safety factor is the ratio between the allowable stress of the material and the stress that occurs. The minimum safety factor in this research bucket is 4.0 or more for the design of static structures or machine elements that receive dynamic loading with uncertainty regarding some combination of loads, material properties, stress analysis, or the environment [19]. Factor of Safety (FOS) = σ limit / σ von Mises. This means that, at the onset of yielding, the maximum shear stress in pure shear is √3 times lower than the yield stress in the case of simple tension [20].

Based on the results of the analysis of Figure 6 above, the V-3 bucket is the strongest in resisting a load of 33.055 N with the method with a minimum safety factor of 6.945, then the second position is occupied by the V-2 version of the bucket with a safety factor of 6.756, then the last position of the V-1 bucket with the smallest safety factor of 6.656.

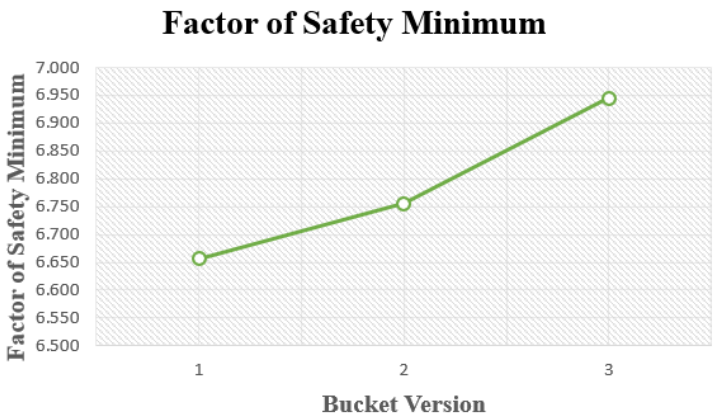


Fig. 7 Factor of safety bucket chart

Summary

- The results of tensile testing of epoxy resin composite materials with fiber content of 0%, 3%, 5%, 7%, and 9% using standard specimen sizes ISO 527 has a large tensile strength is 9% fiber content with a modulus of elasticity 2652.14 N/mm^2, yield strength 18.552 N/mm^2, and tensile strength 32.496 N/mm^2.
- Simulation using solidworks software on the V-1 bucket, V-2 bucket, and V-3 bucket using an epoxy resin composite material with palm fiber produces the V-3 bucket as the best with a stress value of 2.6670575 N/mm^2 far from the yield strength of the material. The strain value of 0.000557 is smaller than the strain value of bucket V-1 and V-2, and the smallest deformation also occurs in bucket V-3 of 0.07922 mm.
- The best design model based on the safety factor value from the largest is the V-3 bucket with a minimum safety factor of 6.945, then the V-2 bucket with a minimum safety factor of 6.756, and the V-1 bucket with a minimum safety factor of 6.656.

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