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Design Optimization of Composite Resin Pelton Turbine Bucket Using Solidworks

By

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Abstract

Micro hydro power plants that usually use Pelton turbines, need to be developed to remote villages to meet electricity demand in the countryside of Indonesia. Pelton turbine buckets that are usually made of metal materials not only should be manufactured specifically, but also need special maintenance caused by easy to rust. The purpose of this study is to design pelton turbine buckets from composite materials which corrosion resistance, light weight, and easier to be manufactured than metal materials. The research began with testing the tensile strength of epoxy resin composite materials reinforced by Sugar palm fibers (SPF) with variations in fiber content of 0%, 3%, 5%, 7% and 9%. Then, the best tensile strength value was used in a simulation of 3 different sizes variant using solidwork, to obtain the best turbine bucket model. The results of this study showed that epoxy resin composite reinforced with SPF a volume fraction of 9% has the best tensile strength, i.e. 32.6054 N / mm2. Then the results of this tensile strength was used in simulations of Pelton turbine bucket geometry with laboratory scale sizes that have been varied to 3 different sizes variant. All simulated bucket variant have a safety factor above 6, meaning that they are resistant not only to static and fluctuating loads, but also to shock loads. This result confirmed that SPFRERC are suitable to be used for manufacturing the Pelton turbine bucket. The best design is V-3 compared to V-1 and V-2 with a minimum deformation of 0.07922 mm, a Stress of 2.6670575 N/mm2, strain of 0.000557, and a safety factor of 6.945.

Index Terms— Bucket, Composite, Pelton Turbine, Safety Factor, Solidworks.

Introduction

The need for energy is increasing every day, the majority of power plants are still utilizing fossil fuels such as coal which has limited provision so that some power plants in Indonesia, had several times almost stopped operating due to lack of coal supply [1]. While the use of diesel power plants in rural areas in Indonesia also causes new problems along with the high cost of fuel. Therefore, the use of small-scale water energy as a source of electricity is very useful, especially in areas that have large water resources and are in the highlands, as shown in Figure 1(a), which shows the swift flow of rivers in a village in southeast Aceh. In this case, the right power plant is a Micro hydroelectric Power Plant (MHPP), i.e. a small-scale hydroelectric power plant that produces small power (10-150 kW) which is suitable for Pelton turbines [2].

Some of the swifting flow of the rivers has been utilized by using a simple waterwheel whose material is made of steel. But this also causes problems, because the steel material is easy to rust. Moreover, the water wheel was made in simple design, and without the basis of calculations or software simulations, so that in terms of construction is inadequate. As a result, the lifetime of the waterwheel is not long. Figure 1 (b) shows a broken steel waterwheel in countryside of south-east Aceh.

Pelton turbine is one type of water turbine whose working principle utilizes water potential energy to generate electrical energy. The working principle of Pelton turbines is to utilize fluid power from water to produce shaft power [3]. Then, the rotation of this turbine shaft will be converted by the generator into electric power.

Figure 1 *(a) The swift flow of rivers in a countryside of southeast Aceh. (b) A damaged waterwheel at the edge of the river*

Pelton turbine buckets (PTB) that are usually made of metal materials not only should be manufactured specially, but also need special maintenance caused by easy to rust. Obviously, It is not suitable to be used in remote villages. Therefore, it is necessary to look for other materials for PTB which easier to be manufactured, not easy to rust and also do not require special maintenance, i.e.: composite materials. The purpose of this study is to design pelton turbine buckets in Laboratory scale from Sugar Palm Fiber Reinforced Epoxy Resin Composite (SPFRERC) which corrosion resistance, light weight, and easier to be manufactured than metal materials. It is hoped that in the future further research can be carried out to be applied to actual measures that can be used in rural areas.

The PTB has a concave-shaped that causes the water flow velocity to change into a force that provides torque to rotate the turbine wheel. Therefore, the PTB must be strong enough to withstand the forces caused by changes in the momentum of the water flow from the nozzle.

Fiber mixed with Resin forms a composite material. The resin as a matrix serves as a binder as well as a protector of the composite structure, gives strength to the composite and acts as a Stress transfer medium received by the composite and lower weight, increased rigidity and strength, low thermal distortion compatible with face sheets, absence of galvanic corrosion Corrosion [4]. While natural fibers for example palm fiber is used as a reinforcement in composite materials so that the composite produces a new material that is light and strong [5][6][7].

Indonesia has many types of natural fiber that are abundant. Some natural fibers become unused organic waste [8]. Although the use of natural fibers as reinforcement in composite materials has been widely studied, their use is still limited because natural fibers have their own advantages and disadvantages [6][7][9][10].

Method

The research process for optimizing material bucket design using composite materials is shown in Figure 1.

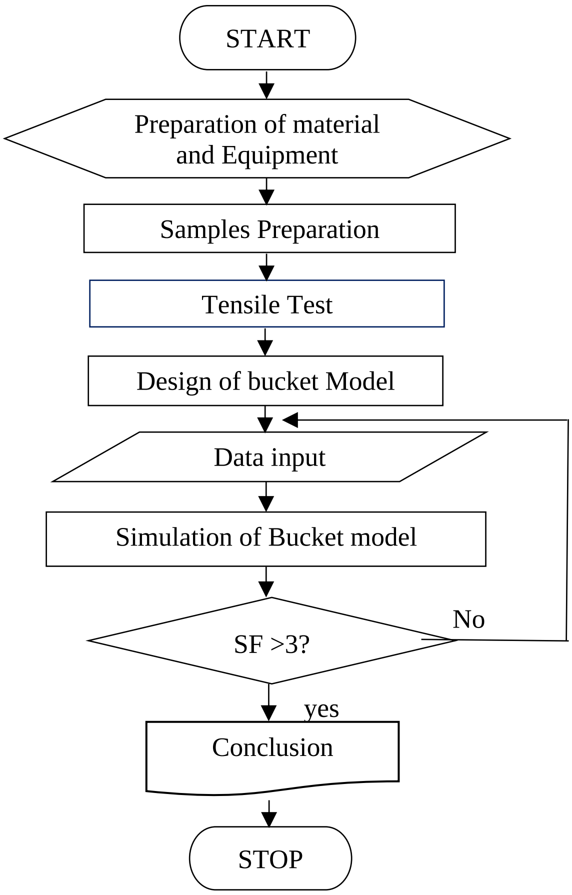


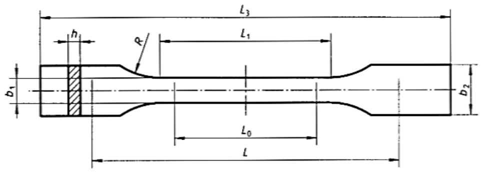
Figure 2: *Research Flowchart*

Preparation of Materials and Equipment

The materials used in this study are palm fiber (Arenga pinnata), epoxy resin, and hardener. The equipment used in this research is Tensile Test Machine, Precision Digital Balance, and Solidworks software for simulation. The Tensile test specimen size follows ISO 527 standard.

The materials used Sample Preparation

The composite samples used in this study were made from epoxy resin as matrices and palm fibers as reinforcements. Specimen molds are made of PLA (Polylactic Acid) material made using a 3D printing machine. The method of making this composite specimen is a handy lay up with long palm fiber with a size of 130 mm - 150 mm. Specimens are made according to the ISO 527 standard size [11] as shown in Figure 3. The dimensions of the specimen made are shown in Figure 3, where the specimen length is >150mm, Gauge length 50+5 mm, Width of narrow portion 10+0.2 mm, and Thickness 2 to 10 mm.



Dimensions in millimetres

l_3	Overall length	⩾ 150 [1)]
l_1	Length of narrow parallel-sided portion	60 ± 0,5
R	Radius	⩾ 60 [2)]
b_2	Width at ends	20 ± 0,2
b_1	Width of narrow portion	10 ± 0,2
h	Thickness	2 to 10
L_0	Gauge length (recommended for extensometers)	50 ± 0,5
L	Initial distance between grips	115 ± 1

Figure 3: *Specimen size based on ISO 527 [11].*

The Tensile Test conducted in this study using Tensilon RTF 2410 Universal Testing Machine. The samples consists of 5 condition with 5 samples for every condition.

Results and Discussion

Simulation using static methods, in simulation is given a loading of magnitude according to the following equation:

$$F = \frac{P}{2\pi \,.\, R \,.\, n} = \frac{29.81\ \text{Nm/s}}{6.28 \,.\, 0.08975\ \text{m} \,.1.6\ \text{r/s}} = 33{,}055\ \text{N} \quad (1)$$

where
P: Power (Watt)
T: Torque(N.m)
w: angular velocity (rad/s)
R: Radius (meter)
F : Force (Newton)
π : 3,14
n : rotation speed (rpm)

Table 1: *The Tensile strength of specimen with 9% volume content*

No.	Max Load [N]	Tensile Strength [N/mm^2]	Elastic Modulus [N/mm^2]	Yield Strength (N/mm2)
1	1417.2	32.496	2315.9	19.18
2	1521.8	35.884	3289.4	19.91
3	1384.1	33.158	2791	19.89
4	1303.5	29.01	2492.6	15.76
5	1296.2	32.479	2371.8	18.02
				18.55

Table 1 shows The result of Tensile strength, Elastic Modulus and Yield Strength from 5 specimens with a fiber content volume of 9%. The table shows that the average yield strength of 5 samples is 18.55N/mm^2.

Bucket Geometry

Pelton turbine bucket geometry with laboratory scale sizes in this study have been varied into 3 different sizes, i.e.: bucket width (b), bucket height (h), and bucket height (h_1) [12].

b = 3.0, 2.7, and 3.2 (2)
h = 2.7, 2.5, and 2.1 (3)
h_1 = 0.19, 0.25, and 0.35 (4)

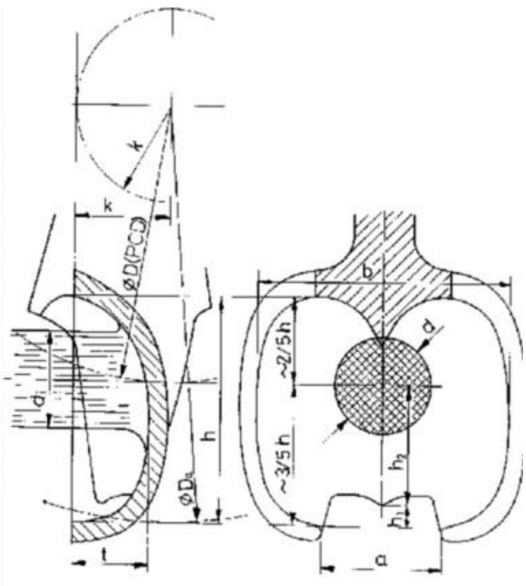


Figure 4: *Bucket dimensions*

Figure 4 shows the dimension of the Pelton turbine bucket. The diameter of the nozzle affects the dimensions of the pelton turbine bucket construction. To determine the optimal jet diameter (d) related to previous studies using the following equation [13][14][15][16]:

$$d = \sqrt{\frac{4 \times Q}{\pi \times C1}} \quad (5)$$

Information:
d: Optimum diameter of nozzle (mm)
Q: Capacity (m^3/s) C_1: Absolute velocity of the jet (m/s)

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

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

$$= 0.01199\ m = 12\ mm$$

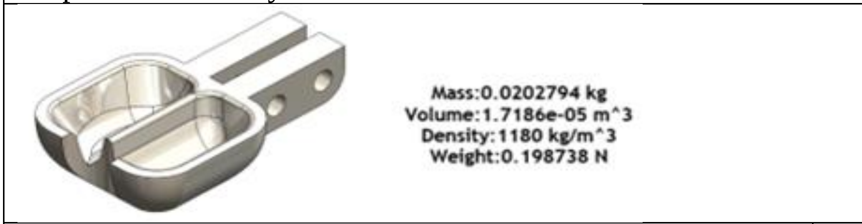
Table 2: *Dimension of bucket model*

Item	V-1 [mm]	V-2 [mm]	V-3 [mm]
Bucket width (b)	35.9	32.4	38.4
Bucket height (h)	32.4	30	25.2
Bucket hole height (h1)	2.3	3	4.2

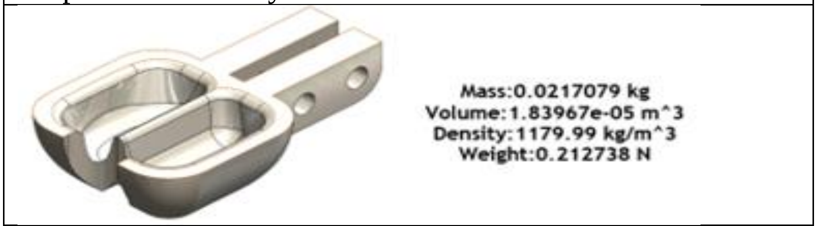
Bucket size and geometry analysis

The sizes of 3 bucket models V-1, V-2, and V-3 are shown in Table 2, each of which consists of bucket width (b), bucket height (h) and bucket hole height(h1). Simulations are carried out using solidwork which is already widely used in analyzing and simulating various designs in various engineering applications, designing a product, machine or tool [17].

Properties Geometry of Bucket V-1



Properties Geometry of Bucket V-2



Properties Geometry of Bucket V-3

Figure 5: *Bucket geometry specifications*.

Data analysis

There are 3 data analyzes resulting from this research, which are as follows:

a. The results of tensile strength, yield strength, and modulus of elasticity of fiber-reinforced epoxy resin composite materials were obtained from the specimen test results, which were implemented into the Pelton turbine bucket geometry.
b. Values of stress, strain, and deformation occurring in Pelton turbine buckets from 3 different designs using Solidworks software.
c. The safety factor of the bucket.

Independent of Mesh

The validity of this study was tested using the Independent of mesh method in order to produce accurate results and reduce the simulation time with the Solidworks software [18]. Independent mesh is done so that the final result is efficient in calculation time and accurate in results, because the bigger the element size is the faster the simulation time but the results are inaccurate, whereas the smaller mesh size the simulation time is too long [19]. Therefore, the Independent of mesh method is carried out as shown in Figure 6.

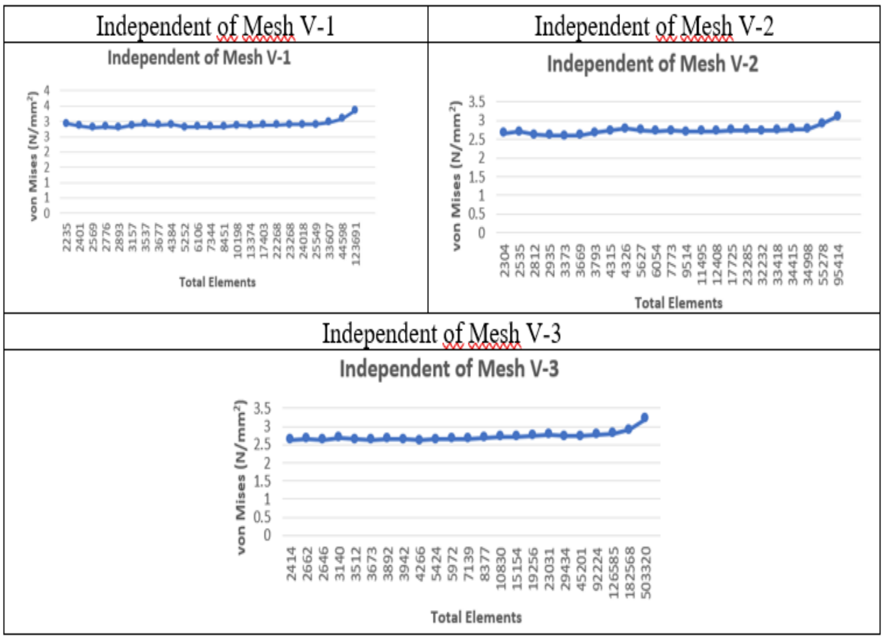


Figure 6: *Independent of Mesh*

Based on Figure 6, the points that are in a stable condition are taken, as listed in table 4.

Table 4: *Bucket mesh size*

Bucket model	Ukuran Mesh [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 safety factor

Figure 7 shows the results of the deformation that occurred in the simulation of 3 buckets model of SPFRERC which was subjected to a load of 33.055 N.

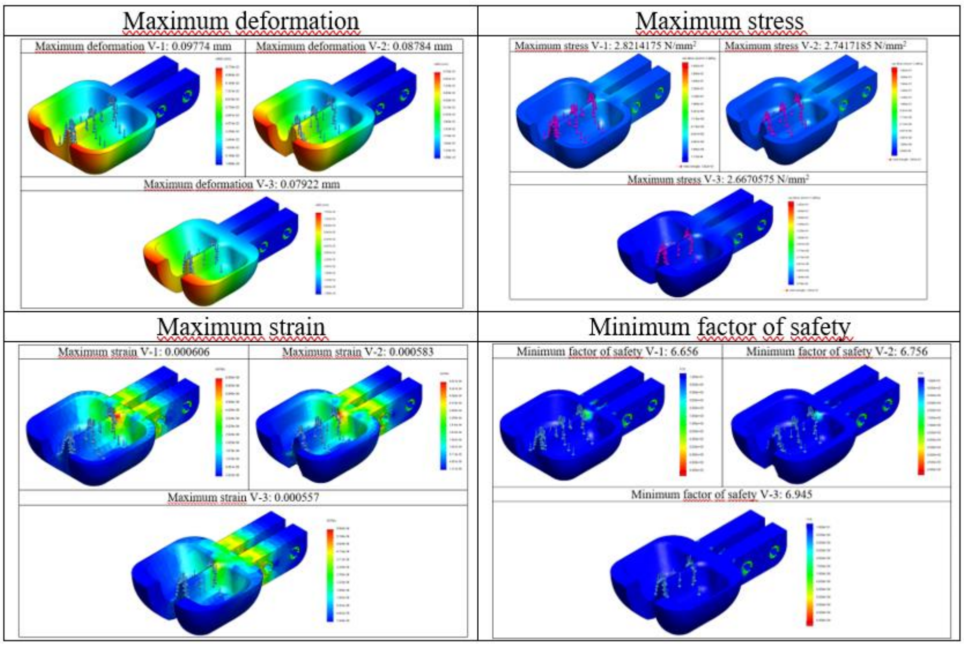


Figure 7: *Bucket simulation results*

Based on the simulation results as shown in figure 7, the V-3 bucket model experiences the least deformation, because it is slightly thicker than other models.

The results of the analysis shown in Figure 7, the V-3 bucket is the strongest with a load of 33.055 N with a method with a minimum factor of safety of 6.945, then the V-2 design with a factor of safety of 6.756, and finally the lowest is the V-1 design with safety factor of 6.656.

Figure 8: *Bucket factor of safety graph Conclusion*

Conclusion

From the results of this study, it can be concluded that:

1. The results of tensile testing of SPFRERC using standard specimen sizes ISO 527 with a content of 0%, 3%, 5%, 7%, and 9% found that the greatest tensile strength, 32.496 N/mm2 was obtained at 9% fiber content, with a modulus of elasticity of 2652.14 N/mm2, and a yield strength of 18.552, N/mm2.
2. Simulation using Solidworks software on V-1, V-2, and V-3 bucket model using SPFRERC resulted V-3 bucket model as the best design with a lowest stress. The value of the yield strength of the material of 2.6670575 N/mm2. The strain value of 0.000557 is smaller than the strain value of the V-1 and V-2 buckets, and the smallest deformation also occurs in the V-3 bucket of 0.07922 mm.
3. Based on the factor of safety value, the best design is the V-3 with a minimum factor of safety of 6.945, followed by the V-2 bucket with a minimum factor of safety of 6.756, and the V-1 bucket with a minimum factor of safety of 6.656.

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