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INFLUENCE OF SAND GRADATION ON VOLUMETRIC WEIGH AND COMPRESSIVE STRENGTH OF PAVEMENT FOAM MORTAR

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Abstract

Foam mortar is a substitute for sub-base layers and base layers in road pavement construction on peat soil , which has the advantages of lightness, strength, and self-compacting. Sand is one of the building blocks of foam mortar. The purpose of the study was to analyze the effect of the gradation of sand on the resulting physical and mechanical properties of foam mortar (foam concrete). In this research, six gradations of sand were made (gradations of 3 sand sources and 3 gradations based on pusjatan standards) and then used in the manufacture of foam mortar and analyzed for volumetric weigh and compressive strength. Foam mortar from the six gradations of sand, it is concluded that gradation no. 6 (lower limit of pusjatan gradation) with a value of volumetric weigh is 0.97 t/m^3 does not float perfectly in water, and no. 1 to 5 (gradation of 3 sand sources and 2 gradations of Pusjatan upper limit and middle) with a volumetric weigh is 0.83 t/m^3 - 0.93 t/m^3 floats in water. The compressive strength values of the 6 gradations are above 2000 kPa and can be used as foundation layers in road pavements.

Keywords:

Sand Gradation;
Foam Mortar;
Volumetric Weigh;
Compressive Strenght.

1 Introduction

Indonesia is a country with a lot of peat soil. One of them is Riau province. On the island of Sumatra, the largest peatland is found in Riau province covering an area of 4.004 million ha (56.1% of the land area of Sumatra island or 45% of the land area of Riau province), the high carbon content of peat soil in Riau is the highest in all of Sumatra and even in Southeast Asia [1]. Peatlands in Riau Province cover an area of 5.09 million ha (56.42% of the total peatland area on the island of Sumatra), which has the potential to store +14,605 million tons of carbon. Peat depth can reach 16 meters. Peat consists of organic fragments from vegetation that have changed and fossilized chemically, the accumulation of this organic material forms peat soil [2].

Although foam concrete has been utilized for highway construction in the UK since 1970, it took the material roughly ten years to gain acceptance as a viable building material [3]. In the recently constructed industrial zone in Hertfordshire, UK, foam concrete was used as the foundation material for highways. The original subbase was made of peat, which combined with the area's high phreatic surface produced several floods. Drainage had to be put in place both before and during construction. The road's common structure could not be used since repeatedly wetting and drying separate building layers would harm the road's already-completed structure [4].

To prevent damage to roads on peat soil that has a low bearing capacity and frequent subsidence, Pusat Penelitan Jalan dan Jembatan (PUSJATAN) developed a foam mortar technology in 2013 called Foam Mortar Lightweight Technology (FMLT). FMLT is used as a substitute for backfill soil and foundation layers, which has the superiority of being lighter than water, not prone to landslides, and has a strength of > 800 kPa for soft soil substitutes and > 2000 kPa for road foundation layer substitutes. So when used on peat soil it does not give a large load resulting in no large decrease in peat soil [5].

The following are the key benefits of foam concrete structures [6] :

• Easy and quick pouring: This type of pouring may generate and implement 400–600 cubic meters of installation per day, resulting in a considerable reduction in construction time and expense.

• Complete filling of pores and cavities without compaction - foam concrete has the benefit of filling all of the cavities, which also makes it somewhat self-leveling.

• Good absorption qualities: The fine cell structure of foam concrete enables it to absorb kinetic energy during upper construction settlement or compression.

• Low failure rate: Unlike some artificially lightened materials, foam concrete is not prone to failing because of the presence of fungi, bacteria, or hydrocarbons.

• Eco-friendly in terms of production and use

Foam concrete has sufficient strength, according to research by Jalal et al. [7], to be utilized as a building material for industrialized building systems without vibrating or compacting to fill holes and cavities across a considerable distance. In addition to superior thermal insulation [8], outstanding freeze/thaw characteristics, and exceptional fire resistance, it offers quick and settlement-free construction. The production of building blocks and wall panels, thermal insulation, monolithic low-rise and individual house building, road sub-bases maintenance of bridge abutments, ground stabilization, and sound and thermal proofing insulation of floors are among the uses for foamed concrete [9-11]. It is also used for thermal protection of flat, monopitched, and double-pitched roofs.

A stable foamed concrete can be produced by utilizing a variety of techniques, including foam preparation, foam agent type, mixture accuracy, surfactant and additive type, mix design, etc. There are no established techniques for designing foam concrete. Concrete's consistency varies with the amount of water it contains and shrinks when it contains more foam [12]. One of the constituent materials of FMLT is sand, so this research will examine the effect of sand gradation on the volumetric weight and compressive strength by using 3 sand sources from Lake sand, Teratak Buluh sand and Rengat sand, then comparing the 3 gradations of sand from Teratak Buluh based on PUSJATAN gradation standards (Upper limit, Middle and Lower Limit). After that, the Uniformity Coefficient (Cu) and Coefficient Curvature (Cc) values of the six gradations are calculated.

2 Experimental Study

2.1 Methodology

The method used in this research is an experimental study in the laboratory by:

1. Make foam by mixing water and foam agent using a foam generator and compressor, with a volumetric weigh of 0.055 to 0.085 t/m3.
2. Make mortar by mixing cement, sand and water. check the sand gradation used according to the upper and lower limits
3. Mix the mortar and foam. Check the flow value 180+- 20 mm
4. Put the foam mortar in a cylindrical mold (diameter 100mm, height 200m)
5. 14 days old test for compressive strength and volumetric weigh foam mortar with a minimum compressive strength value of 2000 kPa and volumetric weigh < 1 t/m3.

a b c d

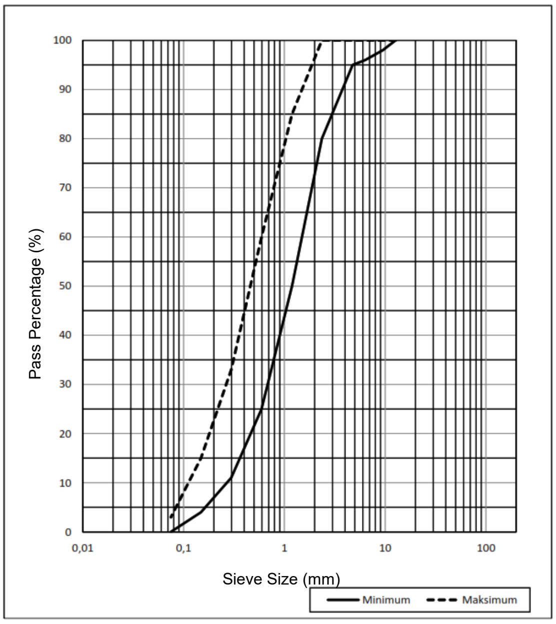
e f g h

Figure 1. (a) Mortar Construction, (b) Foam Production, (c) berat busa , (d) Flow Test, (e) Cylinder Samples, (f) Maintenance, (g) Compressive Strength Test, (h) After Compressive Strength Test

Based on Pusjatan specifications, sand aggregate gradation is in accordance with the figure below.

Sieve		% Weight Passing the Sieve	
		Minimum	Maksimum
No.	[mm]	[%]	[%]
½"	12.70	100	100
3/8"	9.51	98	100
¼"	6.35	96	100
# 4	4.76	95	100
# 8	2.36	80	100
# 16	1.19	50	85
# 30	0.60	25	60
# 50	0.30	11	33
# 100	0.15	4	15
# 200	0.08	0	3

a



b

Figure 2. (a) The percentage of weight passing the sieve, (b) Graphic of sand gradation for foam mortar

2.2 Material

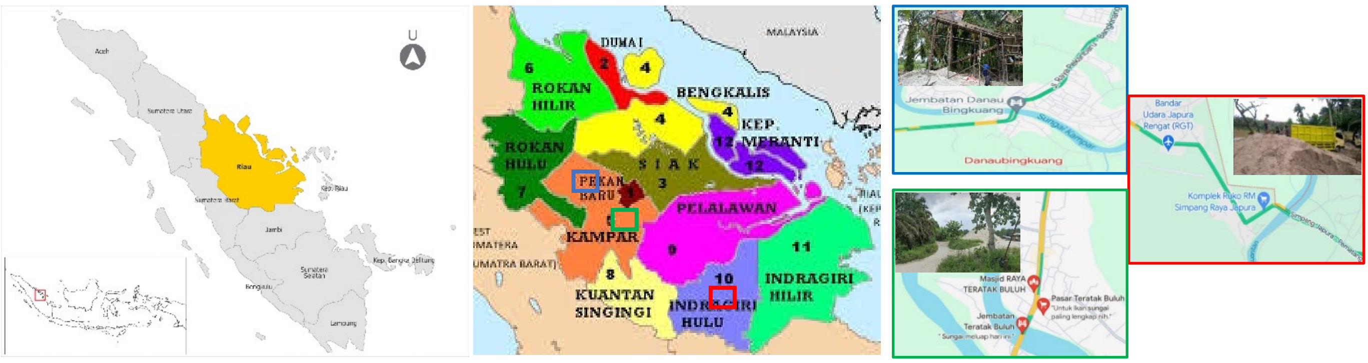
FMLT consists of mortar + foam, where mortar is made from sand, cement, and water. Foam is made from foam agents and water.

The sand used comes from 3 sand sources in Riau province, namely:

1. Lake sand is from the Danau Bingkuang bridge, Kampar Regency.
2. Teratak (Trtk) Buluh sand is from the river near the Teratak Buluh bridge in Kampar Kiri Regency and
3. Rengat sand is from Pasir Ringgit village, Lirik sub-regency, Indragiri Hulu Regency.

The cement used is PCC (Portland Composite Cement) type cement from Semen Padang, West Sumatra, water is from Abdurrab University laboratory Pekanbaru, Riau, and SMACON foam agent.

Foam is made by mixing the foaming agent with water, the ratio is 1:30 then put into the snow wash and then raised with a compressor. The volumetric weigh standard for foam based on pusjatan is 0.0055-0.085 tons/m3. This foam is useful for forming air cavities in mortar [5].



a b c

Figure 3. (a) Indonesia & Sumatera Island, (b) Riau Province, (c) Lake Sand, Trtk. Buluh Sand & Rengat Sand

The material weight of each FMLT component can be seen in Table 1 below:

Table 1. weight of FMLT constituent materials 1 m^3 foam mortar

No	Material	Sumber Pasir					
		Rengat Sand	Lake Sand	Trtk. Buluh Sand	Trtk. Buluh Sand		
		Initial Gradation	Initial Gradation	Initial Gradation	Pusjatan Upper Limit Gradation	Pusjatan Middle Gradation	Pusjatan Lower Limit Gradation
1	Cement	525.000	525.000	525.000	525.000	525.000	525.000
2	Sand	262.583	262.482	262.482	262.482	262.482	262.482
3	Water	262.500	262.500	262.500	262.500	262.500	262.500
4	Foam	34.068	34.346	34.338	34.338	34.338	34.338
	Total	**1,084.151**	**1,084.328**	**1,084.320**	**1,084.320**	**1,084.320**	**1,084.320**

FMLT is a combination of mortar + foam, mortar consists of a mixture of sand, cement, and water, then stirred until evenly distributed. Once it becomes a mortar then add foam and stir until evenly distributed. After homogeneous flow testing is carried out with a discharge value of 18 ± 2 cm, by the provisions of the Minister of PUPR No. 44 of 2015. After becoming a new foam mortar, it is inserted into the cylinder mold [5].

2.3 Sample Number

In this study, samples were made in the form of cylinders with a diameter of 10 cm and a height of 20 cm. The differentiator of this sample is the sand gradation. The number of samples of 18 pieces can be seen in the table below.

Table 2. Number of FMLT Sample

No	Sand Source	Sample Number
1	Rengat Sand Gradation	3
2	Lake Sand Gradation	3
3	Trtk. Buluh Sand Gradation	3

4	Upper Limit of Trtk. Buluh Sand Pusjatan Gradation	3
5	Middle of Trtk. Buluh Sand Pusjatan Gradation	3
6	Lower Limit of Trtk. Buluh Sand Pusjatan Gradation	3
	Total Jumlah	**18**

3 Study Analysis

Sand gradation was carried out on 3 sand sources and added 3 gradations based on PUSJATAN standards with the following information: gradation 1 (rengat sand), gradation 2 (lake sand), gradation 3 (teratak buluh sand), gradation 4 (pusjatan upper limit gradation), gradation 5 (pusjatan middle gradation), gradation 6 (pusjatan lower limit gradation).

Sand gradation is the distribution of sand grain sizes that are filtered using a sieve. In this study, the size of the sieve starts from sieve No ½“, 3/8“, ¼“,# 4, # 8, # 16, #30, #50, #100, #200.

From this gradation test, the uniformity coefficient and gradation coefficient values for the six gradations were obtained. Coefficient of Uniformity (Cu): Is a measure of the uniformity of grain size in the aggregate distribution. A high Cu value indicates a more uniform grain distribution, while a low Cu value indicates a more diverse grain distribution. Coefficient Curvature (Cc): Is a measure of the shape of the aggregate distribution curve. A low Cc value indicates a flatter curve, indicating a more uniform grain distribution, while a high Cc value indicates a steeper curve, indicating a more diverse grain distribution.

Calculation:

These two coefficients are calculated based on the percentage of grains that pass through a sieve with a certain diameter. Here is the calculation formula:

$$\mathrm{Cu} = \frac{\mathrm{D60\ (\%)}}{\mathrm{D10\ (\%)}} \tag{1}$$

D60: The grain diameter at which 60% of the grains pass the sieve.

D10: The grain diameter at which 10% of the grains pass the sieve.

$$\mathrm{Cu} = \frac{\mathrm{D30\hat{}2\ (\%)}}{\mathrm{(D10{*}D60\ (\%)}} \tag{2}$$

D30: The grain diameter at which 30% of the grains pass the sieve.

In this gradation, it will be concluded which gradation can produce FMLT with a compressive strength of > 2000 kPa and a volumetric weigh of < 1 t/m3. So that this sand gradation will later become a reference in making FMLT.

The volumetric weigh analysis is obtained by dividing the sample weight (tons) by the sample volume (m3). This is used to determine whether this sample weighs less than water (< 1 t / m3) so that if this sample is put into water it will float. This is following the FMLT standard from PUSJATAN [5]. Where foam mortar in this study as a substitute for the road foundation layer.

$$\text{Volumetric weigh} = \frac{\text{Mass of Sample (Ton)}}{\text{Volume of Sampel }(\mathrm{m}^3)} \tag{3}$$

Volumetric weigh is the weight per unit volume of oven-dried soil, which is usually expressed in t/m3 [5]

Analysis of compressive strength is done by dividing the maximum load (Newton) by the area of the sample base (mm2). The compressive strength analysis was conducted to determine the ability of the foam mortar to withstand compressive loads from above. The compressive strength of this FMLTmust be equal to or greater than the compressive strength of the foundation layer (> 2000 kPa). According to the Road and Bridge Research Center (PUSJATAN) [5].

Formula 2 based on SNI 1974: 2011, Calculation of concrete cylinder compressive strength test [13].

$$\text{Compressive Strength} = \frac{\text{Max Load (Newton)}}{\text{Base Area (mm}^2\text{)}} \quad (4)$$

4 Result and Discussion
4.1 Sand Gradation

Six gradations of sand derived from three sand sources and three gradations of Pusjatan can be seen in the table and figure below:

Table 3. Six sand gradations (3 sand source gradations + 3 Pusjatan gradations)

Sieve		Lake Sand	Trtk. Buluh Sand	Rengat Sand	Pusjatan (Trtk. Buluh Sand)		
		Initial Gradation [%]	Initial Gradation [%]	Initial Gradation [%]	Upper Limit Gradation [%]	Middle Gradation [%]	Lower Limit Gradation [%]
No.	[mm]						
½"	12.70	100.00	100.00	100.00	100	100	100
3/8"	9.51	100.00	100.00	100.00	98	99	100
¼"	6.35	100.00	100.00	100.00	96	98	100
# 4	4.76	100.00	100.00	100.00	95	97.5	100
# 8	2.36	100.00	100.00	100.00	80	90	100
# 16	1.19	89.51	94.77	96,10	50	67.5	85
# 30	0.60	65.91	79.36	82.70	25	42 .5	60
# 50	0.30	32.11	52.59	46.43	11	22	33
# 100	0.15	7.29	13.58	5.85	4	9.5	15
# 200	0.08	1.24	1.70	0.58	0	1.5	3

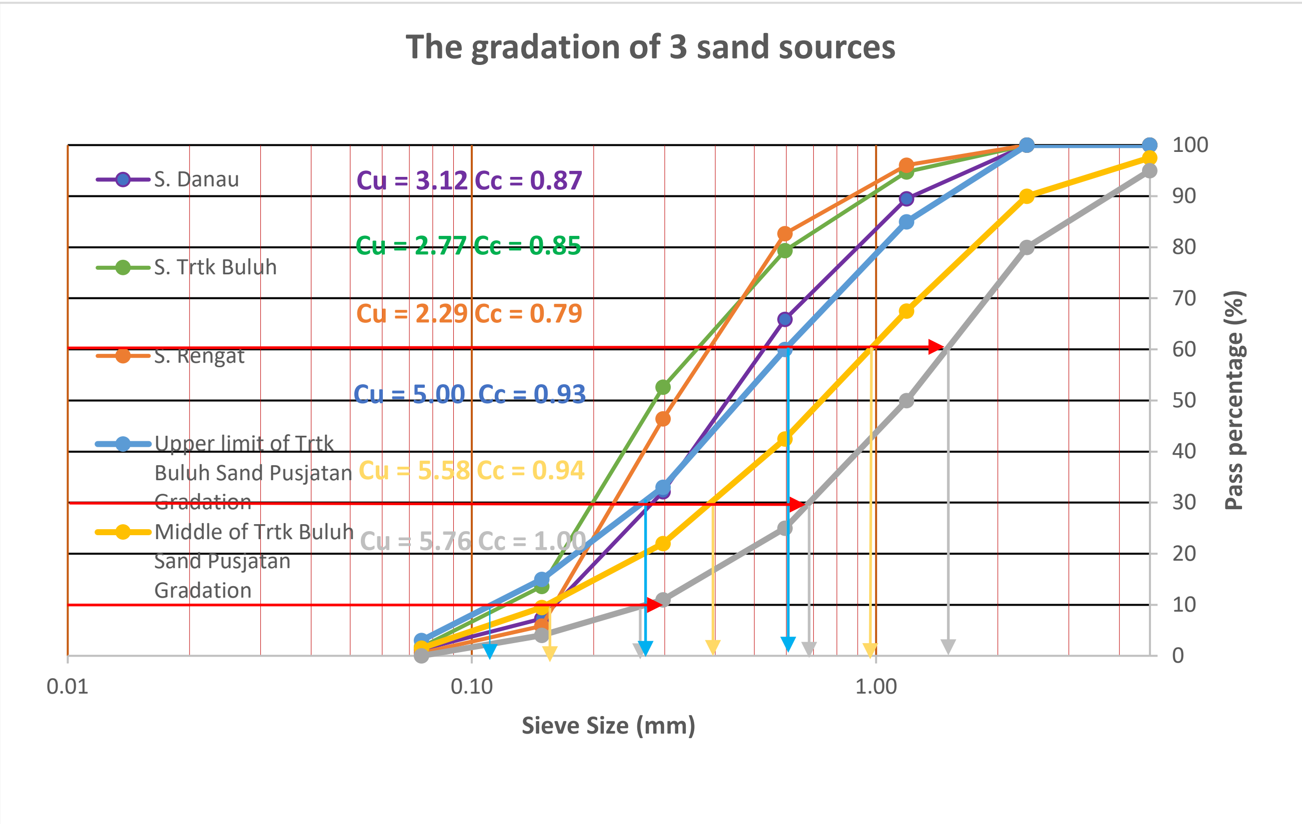


Figure 4. Six sand gradations (3 sand source gradations + 3 Pusjatan gradations)

The gradation of 3 sand sources (Danau Sand, Trtk. Buluh Sand, Rengat Sand) is above the Pusjatan gradation with Cu (uniformity coefficient) values of 2.39, 2.77, 3.12 and Cc (curvature coefficient) values of 0.79, 0.85, 0.87.Three pusjatan gradations (Upper limit, Middle & Lower limit) with Cu (uniformity coefficient) values of 5.00, 5.58 & 5.76, and Cc (curvature coefficient) values of 0.93, 0.94, 1.00. The lower the Cu value, the softer the sand texture. From the figure above it can be concluded that 3 sand sources have the softest sand texture rather then Pusjatan gradation.

4.2 Volumetric weigh and Compressive Strenght

The volumetric weigh and compressive strength are obtained from 18 samples tested (3 samples of each gradation) tested at the age of 14 days of foam mortar the results can be seen in the table and figure below.

Table 4. Volumetric weigh and compressive strength of gradation of 3 sand sources

No	Lake Sand Gradation			Trtk.Buluh Sand Gradation			Rengat Sand Gradation		
	Weight [Gr]	Volumetric weigh [t/m^3]	Compres Strength [kPA]	Weight [Gr]	Volumetric weigh [t/m^3]	Compres Strength [kPA]	Weight [Gr]	Volumetric weigh [t/m^3]	Compres Strength [kPA]
A	1,371.60	0.87	1,953.60	1,418.70	0.90	2,282.08	1,460.80	0.93	3,042.77
B	1,353.60	0.86	2,178.35	1,401.40	0.89	2,333.95	1,481.70	0.94	2,835.31
C	1,332.60	0.85	1,970.89	1,399.80	0.89	2,333.95	1,447.00	0.92	2,212.93
	Average	**0.86**	**2,034.28**	**Average**	**0.90**	**2,316.66**	**Average**	**0.932**	**2,697.00**

Table 5. Volumetric weigh and compressive strength of Pusjatan standard upper limit, middle, and lower limit gradations

No	Gradation of Pusjatan Trtk.Buluh Sand								
	Upper Limit Gradation			Middle Gradation			Lower Limit Gradation		
	Weight Gr	Volumetric weigh [t/m^3]	Compres. Strength [kPA]	Weight [Gr]	Volumetric weigh [t/m^3]	Compres. Strength [kPA]	Weight [Gr]	Volumetric weigh [t/m^3]	Compres. Strength [kPA]
A	1,437.80	0.92	2,403.10	1,425.70	0.91	2,230.21	1,521.00	0.97	2,022.75
B	1,437.00	0.92	2,212.93	1,434.30	0.91	2,403.10	1,523.30	0.97	2,126.48
C	1,437.70	0.92	2,212.93	1,477.10	0.94	2,143.77	1,510.20	0.96	2,575.98
	Average	0.92	2,276.32	Average	0.92	2,259.03	Average	0.97	2,241.74

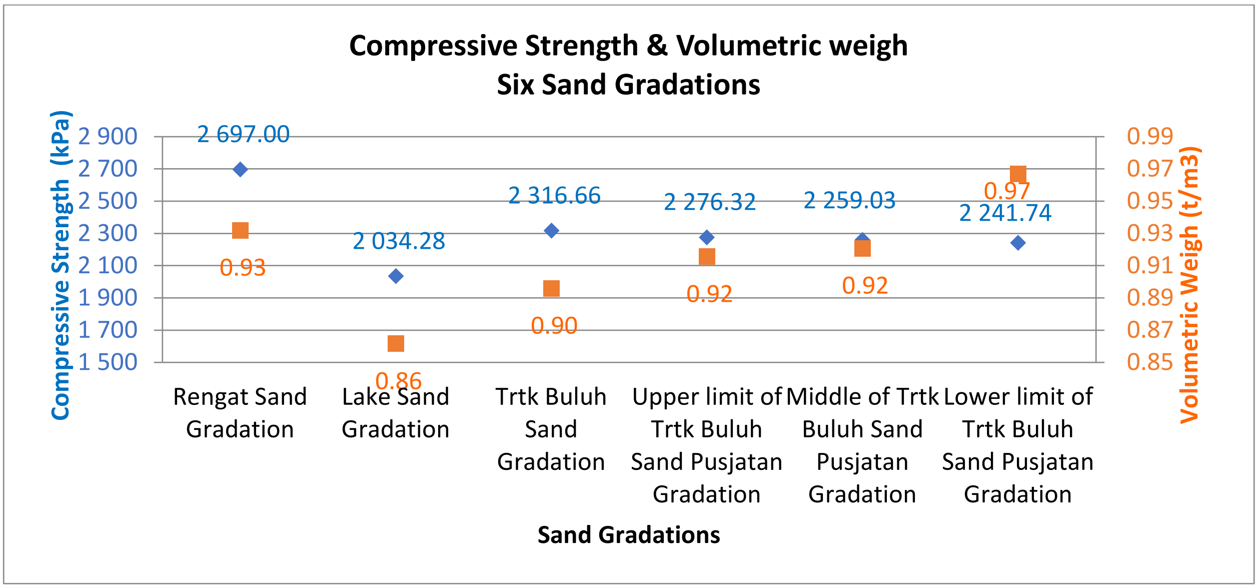


Figure 5. Compressive strength and volumetric weigh of six gradations

From table 4, table 5 and figure 5, it can be seen that Rengat sand has a higher compressive strength with a value of 2,697.00 kPa and a volumetric weigh of 0.93 t/m3. Lake sand has a lower compressive strength with a value of 2,034.28 kPa and a volumetric weight of 0.86 t/m3. The 4 gradations of sand in Trtk. Buluh can be seen that the softer the sand texture, the higher the compressive strength with a lower limit value of 2,241.74 kPa, Middle 2,259.03 kPa, Upper limit 2,276.32 kPa & original condition 2,316.66 kPa and the lower volumetric weigh value is lower if the sand texture are softer with the lower limit value 0.97 t/m3, Middle 0.92 t/m3, Upper limit 0.92 t/m^3 & original condition 0.90 t/m^3. To ensure that the volumetric weight of FMLT is smaller than the volumetric weight of water, FMLT is put into the water. In Figure 6 you can see that FMLT uses 3 sources of sand (Rengat sand, Lake sand, Trtk. Buluh sand) floating in the water. Meanwhile, FMLT uses Trtk. Buluh sand. Reeds with 4 gradations (Trtk. Buluh Sand Gradation, Upper Limit of Trtk.Buluh Sand Pusjatan Gradation, Middle of Trtk. Buluh Sand Pusjatan Gradation, Lower Limit of Trtk. Buluh Sand Pusjatan Gradation) as can be seen in the table above Lower limit gradations do not float perfectly


Rengat Sand


Lake Sand


Trtk Buluh Sand


Upper Limit of
Trtk Buluh Sand
Pusjatan Gradation


Middle of
Trtk Buluh Sand
Pusjatan Gradation
Trtk Buluh Sand


Lower Limit of
Trtk Buluh Sand
Pusjatan Gradation

Figure 6. FMLT samples, six gradations in water

From Figure 6 above it can be seen that the gradation of three sand sources (Rengat sand, Lake sand & Teratak Buluh sand) can float all. Whereas in the pusjatan bottom gradation, the foam mortar samples could not float perfectly and some of the samples even sank.

5 Conclusion

From the results of the discussion and analysis above, it can be concluded as follows:

1. FMLT from 3 sand sources (Rengat sand, Lake sand, Trtk. Buluh sand) the best is Rengat sand with a compressive strength value of 2,697.00 kPa and a volumetric weigh of 0.93 t/m3 and the one that is not good is Lake sand with a compressive strength 2,034.28 kPa and volumetric weigh 0.86 t/m3.

2. The FMLT of the four gradations of Trtk. Buluh sand (1 initial gradation and 3 Pusjatan gradations) can be concluded:
   a. The softer the sand texture in making FMLT, the lower or lighter the volumetric weigh value
   b. The softer the sand texture in making FMLT, the higher the compressive strength.
   c. FMLT from Lower limit Pusjatan gradation does not float perfectly with a volumetric weigh value of 0.97 t/m^3

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