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Experimental study on foam concrete as a sub-base layer of rigid pavement

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Abstract. Rigid pavement consists of three main layers, the base, sub-base and subgrade. Engineers mainly prefered choosing rigid pavement for heavy load road construction because the concrete mixture in this type of pavement has advantages in terms of strength, durability and design life. However, rigid pavement also has several disadvantages: relatively high construction and maintenance costs. As time goes by, researchers have developed several modified concrete mixtures; one of them is foam concrete. Foam concrete has strength similar to concrete in general but with a lighter mass and more affordable construction cost. This study examines foam concrete's mechanical properties and properness as a sub-base layer on a rigid pavement. The research was conducted experimentally in the lab with five different densities of foam concrete mixture. The results showed that sample with a density of 1.0 g/cm^3 has passed the minimum compressive and flexural strength values at 0.896 MPa and 0.0059 MPa respectively. This also indicates that increasing the density of a foam concrete mixture may increase its compressive and flexural strength but also lose its advantage of being a lightweight material as more density means more weight. Thus, it can be concluded that using foam concrete as a sub-base layer of rigid pavement is more advantageous in implementing rigid pavement construction.

1. Introduction

Roads are one of the most commonly used transportation infrastructures in Indonesia. According to data from the Indonesian Central Statistics Agency, as of 2020, the growth in the number of road users in the last five years has increased by an average of 4.95% [1]. This growth increases with the increase in population every year. The highway functions as a liaison between one region and another, and has a major role in improving the economy and development of a region. The most important aspect of highway infrastructure is pavement. Pavement is designed according to the amount of traffic load and the design life. High population growth can cause the pavement to damage faster and shorten its life. This will indirectly increase the maintenance cost per year for the pavement. One type of pavement that is more recommended for high traffic loads and has relatively low maintenance costs is rigid pavement.

Rigid pavement is a type of pavement with the main material being a mixture of concrete and reinforcement and has a relatively low maintenance cost [2]. Rigid pavements require lower overall costs than flexible pavements. This is due to the longer design life and lower maintenance costs, even though the initial construction costs are more expensive than flexible pavements [3]. According to Ketema [4], in the design life span of 40 years, rigid pavements have an adequate period, excluding maintenance and rehabilitation, which is longer than flexible pavements (37.5 and 26 years). In addition, rigid pavements also have advantages such as less hydroplaning and enhanced night vision, which serve to increase safety and reduce the number of accidents that can occur [5]. Rigid pavements are more suitable for road design with high traffic and vehicle loads [2,5,6,7], ports or airports [8-10].

Rigid pavement structures generally consist of 3 layers arranged on a subgrade: surface, sub-base and base. Each layer plays a role in absorbing the stress obtained from the vehicle load and then spreading it to the layer below it to the subgrade [6]. The sub-base is an essential part of the pavement structure and road serviceability. The sub-base layer contributes almost 45% of the total pavement structure for stability against failure [11]. The function of the sub-base layer on the pavement is to reduce the subgrade tension, prevent the entry of fine grains from the subgrade to the surface layer, and serve as a drainage layer if there is no drainage layer underneath [12]. Weak and poor sub-base layers can cause a decrease in stiffness, permeability, and freeze-thaw (F-T) durability of the pavement structure [13]. Rigid pavement layer in general can be seen in figure 1.

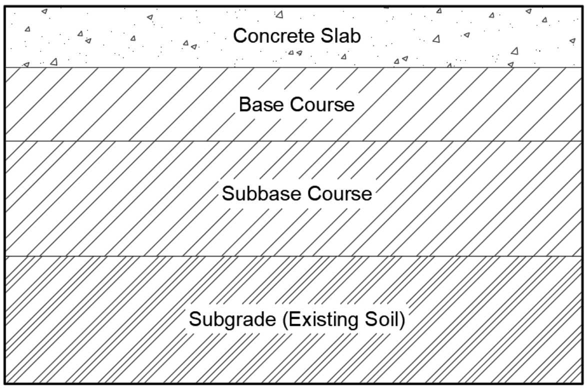

Figure 1. Rigid pavement layers in general.

Several researchers have conducted various studies to address the problem of weak sub-base. Harianto [14] investigated the performance of the sub-base layer with geogrid reinforcement and soil stabilization with additives. His research shows that adding a geogrid to the sub-base layer increases the compressive strength and CBR values, reducing lateral displacement and resistance to tensile stress due to vehicle loads. Farooq [12] investigated the effect of the composition and gradation of aggregate in the sub-base on the characteristics of the layer. The results showed that mixing 5-6% non-plastic fines in the sub-base would increase the density capability, produce a strong layer and good drainage and reduce the required base course thickness. Coban [13] investigated the use of large stone sub-base (LSSB) and geotextiles in the sub-base layer to improve stability, drainage, stiffness and permeability of the sub-base layer. The results showed that the sub-base using LSSB and geotextiles at a certain thickness had higher stability and stiffness. In addition, the use of LSSB provides higher structural support so that it has the potential to reduce rutting and soil pumping issues in the subgrade.

Most research and case studies focus on solving sub-base problems in granular sub-base conditions. Sub-base Granular is a common choice, easy to perform and inexpensive. However, the drawback of using a granular sub-base is that the soil in general has stability and permeability that are difficult to control. The solution to overcome this problem is to look for alternative sub-base materials, such as foam concrete.

Foam concrete is a type of lightweight concrete with self-compacting properties. The final result is a hollow sample due to the reaction of the foaming agent mixed with water which results in the formation of air bubbles when mixing the material. Foam concrete has a density range from 600 kg/m^3

to 1800 kg/m^3. Foam concrete has been widely used in various types of structural and infrastructure construction such as road and airport pavement works [15,16,17], bridge abutments [18], building foundations [19], retaining walls [20] and tunnel construction [21].

Foam concrete consists of several main materials: cement, fine aggregate, water and foaming agent. Foam concrete can be made using various combinations and types of cement, but the cement must be free from lumps and coarse grains [22]. The FC design mix is recommended for its high workability and short setting time. One of the best types of cement to meet these criteria is Portland Cement [23]. Fine aggregate works as a filler in FC mixtures. There are several materials commonly used as fillers in FC mixtures other than sand, such as fly ash, bottom ash, limestone [24], POFA [25] and blast furnace sag [26]. The choice of filler type and gradation can affect some FC characteristics. Fillers with finer gradations tend to produce FC with a more stable mixture consistency and higher compressive strength at the same density [27]. Foaming agent is a mixture that has a major role in the mix design of FC, such as providing air voids in the mixture, increasing the stability of the mixture and increasing the mechanical properties of the FC without a significant increase in weight [23]. In addition, the foaming agent also functions to regulate the density of the FC mixture by controlling the rate of formation of air bubbles in the FC [28]. Foam agents are divided into two types, namely protein-based and synthetic foams. These two types of foam have differences in several characteristics, such as density and foam's ability to expand. Protein-based foams have a higher density than synthetic ones, around 80 kg/m^3 and 40 kg/m^3. Thus, this foam has relatively higher strength and stability than synthetic foams [29]. However, synthetic foam is more recommended in the case of mix design FC with a density above 1000 kg/m3 because it has a higher expansion ability than protein-based foam without containing too high a density [30].

Most of the research conducted about FC as a sub-base material is for the case of flexible pavement. One of them were done by Oyeyi in 2019. Oyeyi [15] conducted an experimental study to determine the potential of FC as an alternative sub-base in flexible pavements. Foam concrete's potency is determined by comparing several parameters such as compressive strength, freeze-thaw resistance, and pressure level between flexible pavement with granular sub-base and FC. His research shows that flexible pavement with an FC sub-base has adequate compressive strength and better freeze-thaw resistance than a granular sub-base.

This study aims to fill the research gap in determining the mechanical properties of foam concrete as a sub-base layer for rigid pavement conditions. Then, chooses the best foam concrete composition based on the requirement in Indonesian Standard on The Use of Foam Concrete for Road Embankment Material.

2. Research methodology

The materials needed in the FC mix design in this study were PCC cement with type CEM I 42.5 N, fine aggregate (sand), water, and foaming agent. Before doing the mix design, the sand will be tested for some basic properties such as specific gravity, water content, volume weight, sieve analysis, organic content and silt content. Fine aggregate testing standards refer to ASTM C136 [31], ASTM C142 [32], and ASTM C40 [33].

The mix design in this study uses density variations which are divided into two sample groups for two types of mechanical properties testing (compressive and flexural) at five types of densities, namely 1.0, 1.2, 1.4, 1.6, and 1.8 g/cm^3. FC samples for the compressive strength test were made in the form of cubes with a side length of 15 cm each. The flexural strength test sample has the same density variation as the compressive strength test but with a different sample size, namely a beam with a length of 60 cm and a square cross section of 15 cm. Compressive and flexural strength can be seen in Figure 2.

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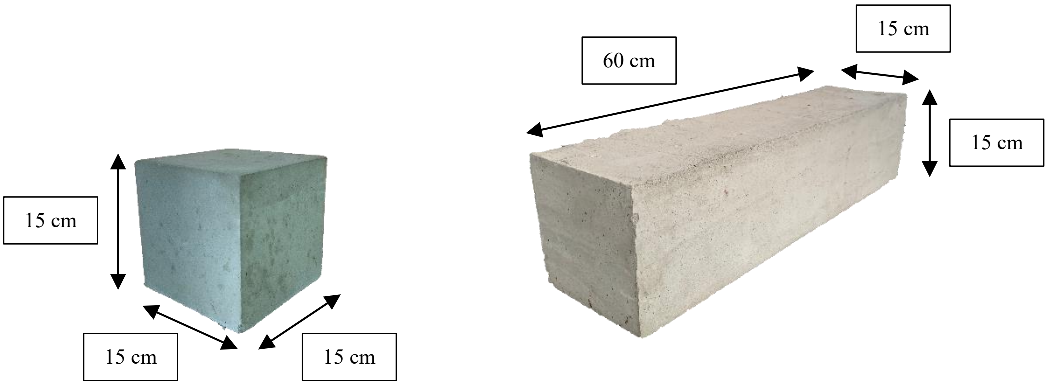

Figure 2. Compressive (left) and flexural (right) strength test sample.

The compressive and flexural strength test refers to BS EN 12390-3 [34] and BS EN 12390-5 [35]. Compressive and flexural strength can be seen in figure 3. Both tests required three samples per density and were tested on day 28 of curing. The compressive strength test is carried out by providing a uniform pressure load on the test sample that has been cured, dried and weighed previously. The loading is carried out until the sample experiences cracks or a decrease in the compressive strength reading. The compressive strength of the sample is determined by dividing the value of the pressure that the sample can accept by the cross-sectional area that receives the load. The flexural strength test has the same concept of loading as the compressive strength test, but the load is applied to the longitudinal center of the sample beam. The sample is pressed until it breaks and then the length of the fracture crack in the sample is reviewed. The pressure reading data and the length of the fracture are then processed to determine the flexural strength of the sample

Figure 3. Compressive (left) and flexural (right) strength test equipment.

3. Result and discussion

Based on the results of the sieve analysis test in figure 4 and table 1 the fine aggregate used in this study has a fairly diverse gradation. The results of other property tests such as water content, specific gravity, mud content and specific gravity can be seen in table 2.

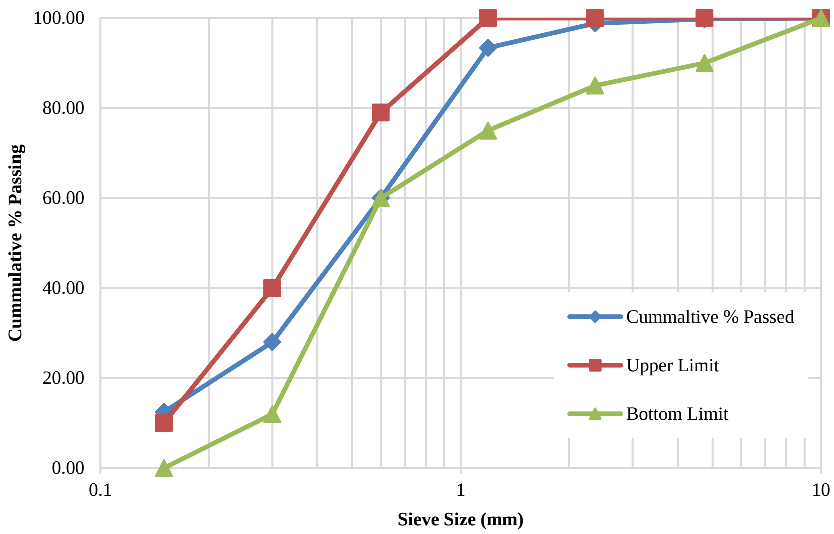

Figure 4. Fine aggregate sieve analysis graph.

Table 1. Fine aggregate sieve analysis detail.

Size No.	Sieve Size (mm)	Weight Retained (g)	Weight Retained (%)	Cummulative % Retained	Cummulative % Passed
No. 4	4.80	1.105	0.22	0.22	99.78
No. 8	2.36	4.81	0.96	1.18	98.82
No. 10	2.00	27.02	5.41	6.60	93.40
No. 30	0.43	166.59	33.36	39.96	60.04
No. 60	0.18	159.98	32.04	71.99	28.01
No. 100	0.15	77.575	15.54	87.53	12.47
No. 200	0.08	50.66	10.15	97.68	2.32
Pan		11.61	2.32	100.00	0.00
Total		499.35	100.00	207.26	

Table 2. Fine aggregate properties.

Testing Item	Results	Standard Range
Finess Modulus	2.07	1.5 - 3.8
Specific Gravity		
- Apparent Specific Gravity	2.71	2.58-2.83
- Bulk Specific Gravity on Dry	2.64	2.58-2.83
- Bulk Specific Gravity on SSD	2.67	2.58-2.83
- Absorption (%)	1.01	2 - 5
Water Content (%)	4.71	3 - 5
Mud Rate (%)	3.87	< 5
Volume Weight		
- Solid Condition	1544.18	1400 - 1900
- Dry Condition	1450.18	1400 - 1900
Organic Impurities	No. 3	Max No. 3

The compressive and flexural strength of the samples were tested on the 28th day. table 3 and figure 5 show the results of mass measurements along with the value of the compressive strength of each sample.

Table 3. Compression strength test results.

Density Design (g/cm^3)	Size (cm)	No. Sampel	Weight (kg)	Density Calc (g/cm^3)	Weight Load (kN)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
1.0	15	1	3.1	0.919	21.4	0.951	0.896
1.0	15	2	3.13	0.927	21.6	0.960	
1.0	15	3	3.07	0.910	17.5	0.778	
1.2	15	1	3.82	1.132	23.6	1.049	1.003
1.2	15	2	3.76	1.114	21.1	0.938	
1.2	15	3	3.81	1.129	23.0	1.022	
1.4	15	1	4.81	1.425	24.3	1.080	1.124
1.4	15	2	4.87	1.443	26.2	1.164	
1.4	15	3	4.85	1.437	25.4	1.129	
1.6	15	1	5.13	1.520	31.1	1.382	1.233
1.6	15	2	5.06	1.499	26.8	1.191	
1.6	15	3	5.16	1.529	25.3	1.124	
1.8	15	1	5.69	1.686	31.9	1.418	1.367
1.8	15	2	5.75	1.704	27.6	1.227	
1.8	15	3	5.66	1.677	32.8	1.458	

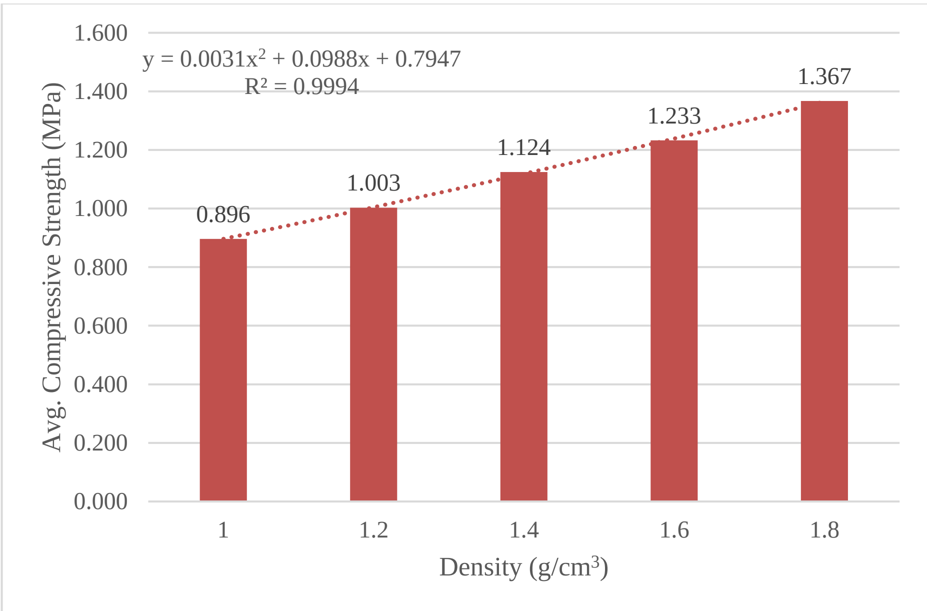

Figure 5. Average compression strength test results per density.

Figure 5 shows that the compressive strength of the sample has a pattern of change. The higher the density of the sample, the higher the value of the compressive strength of the sample. The highest compressive strength value was found in the sample with a density of 1.8 with an average compressive strength of 1.367 MPa.

The sample with a density of 1.8 has a neat and smooth printed surface. As the test progresses, the sample tends to have cracks in the sample and a slight vertical crack straight in the middle until it finally shatters in half when it reaches its maximum compressive strength.

All samples of the flexural test were broken in the middle of the sample so that they met the requirements for calculating the flexural strength according to BS EN 12390-5. The results of the flexural strength test were also found to give the same pattern. The highest flexural strength was obtained in the sample with a density of 1.8 with an average flexural strength of 0.1290 MPa. Table 4 and figure 6 show the results of the flexural strength measurements for each sample density.

Table 4. Flexural strength test results.

Density Design (g/cm^3)	No. Sampel	Weight (kg)	Density Calc (g/cm^3)	Load (N)	Fracture		Flexural Strength (MPa)	Average Flexural Strength (MPa)
					Width, b (mm)	Depth, d (mm)		
1.0	1	11.1	1700	1700	150	154	0.0055	
1.0	2	12.2	2100	2100	150	150	0.0076	0.0059
1.0	3	11.1	1500	1500	150	156	0.0046	
1.2	1	14.5	1.074	3600	150	151	0.0153	
1.2	2	14.6	1.081	3800	158	154	0.0148	0.0138
1.2	3	14.2	1.052	3000	150	159	0.0112	
1.4	1	19.9	1.474	11800	152	154	0.0651	
1.4	2	19.8	1.467	11500	160	155	0.0592	0.0679
1.4	3	19.6	1.452	14500	151	154	0.0794	
1.6	1	20.9	1.548	19500	156	160	0.1021	
1.6	2	20.5	1.519	18200	152	160	0.0959	0.1007
1.6	3	20.5	1.519	18300	160	150	0.1042	
1.8	1	24.0	1.778	20400	155	159	0.1249	
1.8	2	22.4	1.659	21000	157	155	0.1247	0.1290
1.8	3	22.8	1.689	22000	152	155	0.1374	

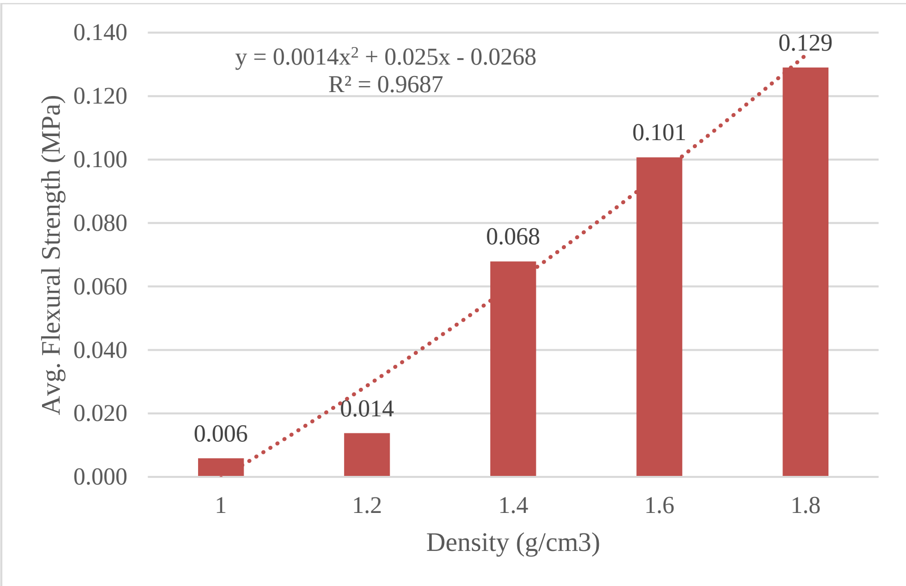

Figure 6. Average flexural strength test results per density.

Indonesian standards only regulate the minimum compressive strength value of foam mortar, not its flexural strength. Flexural strength testing in this study was conducted to determine the flexural behavior of foam concrete as a rigid pavement sub-base layer. The test results show that all variations in the density of foam concrete tested have a very low flexural strength value, almost less than 10% compressive strength. This shows that foam concrete will easily crumble or crack when given a bending load if it is applied as a pavement sub-base layer.

The relationship between density and compressive or flexural strength is best described in polynomial equations. The equation shows an increase in the value of compressive and flexural strength as the density increases. This relationship can occur because samples with high density have fewer air voids because they are already filled with other materials such as sand/cement. The lack of air voids increases the mass of foam concrete, but at the same time increases its mechanical properties.

Based on the Indonesian Standard [36], it is stated that the minimum compressive strength required for the use of foam concrete as a sub-base is 0.8 MPa. The test sample that meets these requirements with the lowest density is the sample of density 1.0 g/cm^3. Thus, the foam concrete mixture is suitable for use in sub-base construction of rigid pavement construction.

4. Conclusion

This study determined the mechanical properties and best composition of foam concrete as a sub-base layer material on rigid pavements. Based on the tests that have been carried out, the test sample with a density of 1.0 g/cm^3 has passed the minimum compressive and flexural strength values at 0.896 MPa and 0.0059 MPa respectively. Thus, it can be concluded that foam concrete can be recommended as an alternative material for the construction of sub-base layer of rigid pavement.

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