Influence of Material Composition on Unconfined Compressive Strength and Elastic Modulus of Foam Concrete

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Abstract. Foam concrete is widely used in lightweight construction due to its low density and high insulation capacity. This study aims to investigate the im- pact of varying material compositions on the compressive strength of foam con- crete, focusing on sand type and curing age. The objective is to optimize its strength characteristics, particularly unconfined compressive strength, for struc- tural applications. The research methodology involves preparing foam concrete samples using two types of sand—Cimalaka and Galunggung—by varying the mix ratios of cement, water, sand, and foam agent. These samples were subjected to unconfined compressive strength tests at different curing periods, specifically 3, 7, and 14 days, to observe strength development over time. Results reveal that both sand types, when mixed in optimal proportions, can achieve compressive strength values exceeding 800 kPa, with Cimalaka sand yielding 990 kPa and Galunggung sand reaching 1000 kPa at 14 days. Additionally, increasing the curing age significantly enhances compressive strength, and a higher cement ratio contributes to a greater modulus of elasticity, making the foam concrete stiffer and less prone to deformation. This research provides valuable insights for improving the performance of foam concrete in construction applications.

Keywords: foam concrete, unconfines compressive strength, material composition

1 Introduction

Foam concrete is an innovative material increasingly used in civil engineering, particularly as lightweight concrete. It is highly suitable for construction in earthquake-prone areas like Indonesia due to its light weight and ability to absorb seismic forces. The use of foam concrete has expanded because of its advantages in providing structural solutions that are both lightweight and efficient in terms of thermal insulation and material consumption.

Foam concrete is created by introducing air voids into the mortar using a foaming agent, which categorizes it as a type of lightweight concrete. It is characterized by its

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low weight, reduced use of aggregate, high fluidity, controlled lower strength, and excellent thermal insulation[1]. These qualities make foam concrete ideal for applications where reducing dead loads is critical, while also enhancing energy efficiency and providing effective thermal insulation.

The production method and materials used play a crucial role in determining the properties of foam concrete. Unlike other types of lightweight porous concrete, foam is generated in advance and then added to fresh cement paste or mortar using a foaming agent[2]. The air voids created by this foam can make up 10–90% of the total volume of the hardened concrete. This porous structure is what defines the material's mechanical properties, including strength, thermal conductivity, sound insulation, and durability. One of the advantages of foam concrete is its weight reduction (up to 80%) compared to conventional concrete[3].

Several researchers have experimented with various mixtures, both with and without the addition of fibers, such as palm fiber[4], water hyacinth[5], sugarcane bagasse ash[6], macro synthetic fibers[7], and others, to test their strength

The objective of this study is to investigate the effect of mixing two different types of Cimalaka sand (CS) and Galunggung sand (GS) on the unconfined compressive strength and deformation of foam concrete. This research aims to determine the optimal material composition to achieve the best performance of foam concrete in construction applications.

2 Method

The research method involves the use of Foam Concrete, which is a mixture of cement, sand, water, and foam to produce lightweight concrete. The use of Foam Concrete in embankments offers significant advantages in reducing settlement and ensuring stability. In this study, foam mixed with mortar is used to create a lightweight embankment material, particularly suitable for road construction and geotechnical applications. The mixture expands up to 2.7 to 4 times its initial volume when foam is added, which minimizes material requirements. Locally sourced materials such as sand were used as the primary aggregate, and the foam agent was incorporated to control the expansion and weight of the material.

The production of Foam Concrete for this research followed specific guidelines and standards. The composition ratio used for the light backfill was 1:1:0.5 (cement ; sand ; water) to achieve the desired properties. Compressive strength and bulk weight limits were set based on Indonesian national standards, ensuring that the resulting mixture met the requirements for road construction. The minimum compressive strength was targeted at 7 kPa, while the maximum bulk weight was limited to 14 t/m^3. These standards ensured the material could effectively reduce soil lateral pressure and perform as a suitable subgrade and pavement foundation. The detailed flow of this research is illustrated in Fig. 1.

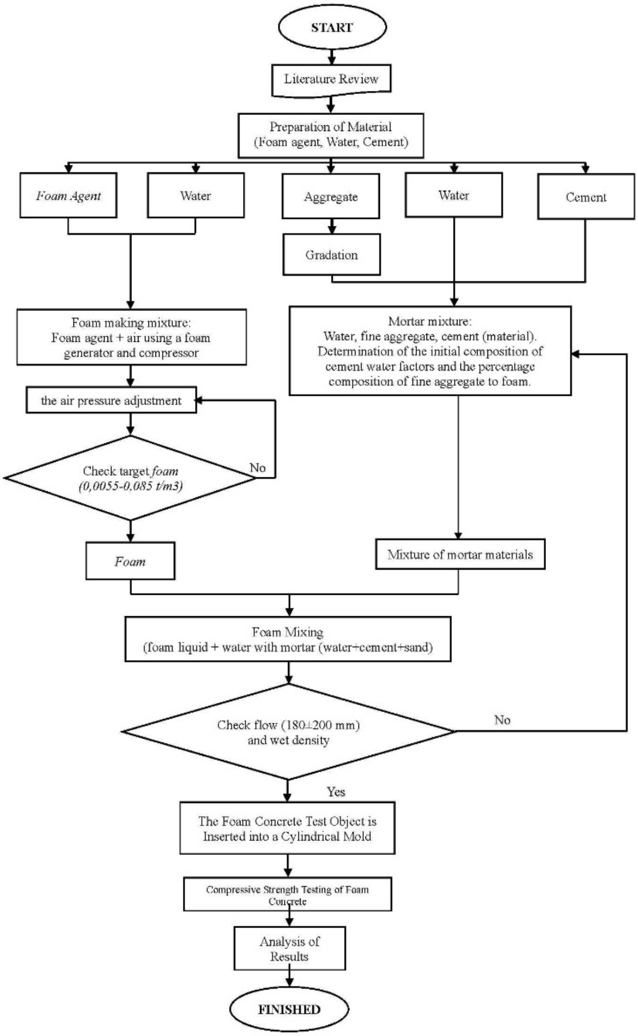

Fig. 1. The flow of this research

Furthermore, the material testing process included using foaming agents and other components in compliance with the relevant Indonesian national standards. Cement, the primary binding agent, was used in accordance with SNI 15-2049-2004[8], while the foaming agent complied with SNI 03-3449-2002[9]. Sand, serving as the aggregate, followed the guidelines of SNI ASTM C136:2012[10], and the water used adhered to the requirements of SNI 7974:2013[11], ensuring the quality and consistency of the foam concrete mixture. The method of producing the foam concrete included ensuring that the mix had adequate hydration for optimal mechanical strength.

3 Results and Discussion

3.1 Physical properties

As shown in Fig. 2, the difference in grain size distribution is quite evident between Cimalaka sand and Galunggung sand. For the same weight and grain size range, Galunggung sand contains a higher fraction of fine particles compared to Cimalaka sand. This difference in physical properties is expected to result in varying compressive strengths when used as a mixture in foam concrete

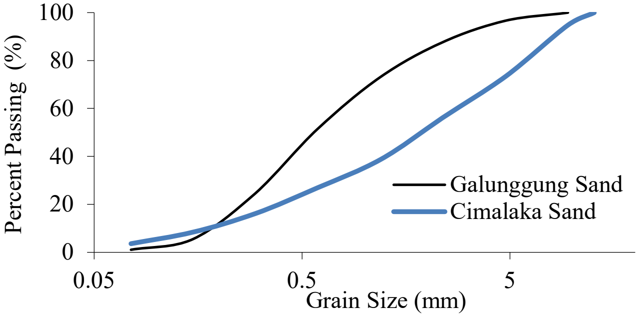

Fig.2 Grain size distribution of Galunggung Sand and Cimalaka sand

Mount Galunggung and Cimalaka are two distinct locations in West Java, Indonesia, known for their sand resources, but they are quite different in both origin and characteristics. Mount Galunggung, near Tasikmalaya, is a volcanic area, and its sand is formed from volcanic materials, resulting in a finer grain size and a higher content of minerals. Cimalaka, located in Sumedang Regency, is farther away and provides sand that comes from more sedimentary processes, making it coarser compared to Galunggung sand. The significant difference in the geological origins of these two places leads to varied physical properties in the sands, which is expected to affect their performance, especially in construction applications like foam concrete mixtures.

The results of the examination of the characteristics of fine aggregates are Cimalaka mountain sand and Galunggung mountain sand. Testing of specific gravity and water absorption of fine aggregate in this study refers to SNI 1970-2016[12]. The following results were obtained as seen in Tabel 1.

Table 1. Pysical properties of Ciamalaka sand and Galunggung sand

Test Type	Cimalaka		Galunggung		Average		Unit
	1	2	1	2	Cimalaka	Galunggung	
Dry bulk density (SD)	2,609	2,626	2,618	2,618	2,617	2,618	g/cm^3
Saturated Dry Bulk surface (SSD)	2,717	2,732	2,665	2,667	2,725	2,666	g/cm^3

Test Type	Cimalaka		Galunggung		Average		Unit
	1	2	1	2	Cimalaka	Galunggung	
Apparent specific gravity (SA)	2,927	2,939	2,747	2,752	2,933	2,749	g/cm^3
Water absorption	4,167	4,058	1,792	1,854	4,112	1,823	%

Based on the analysis of the types of fine aggregate shown in the table above, it was found that the water absorption levels of sand from Mount Cimalaka and Mount Galunggung were below the maximum requirement for fine aggregate absorption, which is 5%. The examination results also indicated that the SSD (Saturated Surface Dry) density of the sand ranged between 2.4 g/cm³ and 2.6 g/cm³. This meets the standards for use as a building material according to SNI 03-1964-1990[13], which specifies a density range of 2.4 g/cm³ to 2.9 g/cm³. Therefore, both types of sand are suitable for construction purposes, ensuring compliance with the required specifications.

3.2 Composition Design

After completing all material testing processes and ensuring they meet the requirements, test objects are created according to a predetermined plan (Job Mix Design). In this research, conducted in the soil mechanics laboratory of the Geotechnical, Tunnel, and Structure Center, the test objects were cylindrical, with a diameter of 10 cm and a height of 20 cm. A total of 54 foam concrete samples were prepared, using different types of sand from Cimalaka and Mount Galunggung. The number of specimens tested for unconfined compressive strength was 3 at the ages of 3, 7, and 14 days.

The Job Mix Design for foam concrete on a laboratory scale aims to determine the optimal mixture of materials to achieve the desired strength of 800 kPa. This process involves experiments and analysis to find the best composition of materials such as cement, water, sand, and foam. The results of the Job Mix Design are crucial, as they ensure that the produced foam concrete meets technical and performance requirements while minimizing the risk of structural failure. Below is the proportion of the laboratory-scale foam concrete material mixture in one batch, with a total of 9 test objects.

Tabel 2. Foam concrete mix proportion for 9 test objects

Types of Sand	Composition	w/c (%)	Material Mixing Proportion Per Mix / 9 Cylinders (material weight per m3 x 0.021206			
			Cement (kg)	Water (kg)	Sand (kg)	Foam (kg)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cimalaka	Comp.1	60	6,362	3,817	6,680	12,893
	Comp.2	62	6,574	4,072	6,553	12,639
	Comp.3	64	6,680	4,284	6,447	12,427
Galunggung	Comp.1	54	6,362	3,435	5,047	13,848
	Comp.2	56	6,574	3,690	5,768	13,275
	Comp.3	58	6,680	3,881	5,683	13,084

3.3 Flow test

Flow testing is conducted to determine if the flowability of the foam mortar material mixture meets the specified requirements, which are 180 mm ± 20 mm. This test is crucial for assessing the quality of the foam mortar, as a high flow value indicates that the material can flow well and is easy to use in construction. The test results are shown in Table 3.

Table 3. flow test results

No	Aggregat	Foam Mortar Material Composition	Flow Value (mm)
1	Cimalaka sand	C. 1 w/c 60%	185
		C. 2 w/c 62%	180
		C. 3 w/c 64%	195
2	Galunggung san	C. 1 w/c 54%	175
		C. 2 w/c 56%	180
		C. 3 w/c 58%	190

3.4 Unconfined test

Unconfined compressive strength testing for foam mortar is a method used to assess the strength of foam mortar material. In this test, a load is gradually applied to the foam mortar sample until it fails. This process helps determine the maximum pressure the foam mortar can withstand before breaking. The results from this test provide valuable information about the material's strength and suitability for use in construction applications, ensuring that the foam mortar meets the necessary performance standards and can handle the stresses it will encounter in practical use. The results of the test can be seen in Table 4. The results of the unconfined compressive strength test for foam mortar indicate that the strength values increase as the test specimens age. Notably, in the third composition using Cimalaka sand and Galunggung sand, the strength at 14 days surpasses the minimum strength threshold set by the lightweight mortar-foam material embankment technology planning module for road construction. This demonstrates the material's potential effectiveness and reliability in practical applications, particularly in meeting the required standards for road construction projects.

Tabel 4. Resume of unconfined compression test results

Types of Sand	Composition	Sample	3 days	7 days	14 days
Cimalaka		1	270	404	439
	Cement 300 W/C 60	2	210	392	424
		3	251	385	440
	Average (kPa)		244	394	434
		1	345	656	722
	Cement 310 W/C 62	2	377	665	716
		3	339	659	737

Types of Sand	Composition	Sample	3 days	7 days	14 days
	Average (kPa)		354	660	725
	Cement 315 W/C 64	1	432	954	973
		2	455	951	989
		3	439	926	1010
	Average (kPa)		442	944	990
Galunggung	Cement 300 W/C 54	1	314	414	533
		2	323	427	521
		3	330	436	536
	Average (kPa)		322	426	530
	Cement 310 W/C 56	1	361	674	737
		2	377	665	753
		3	364	684	766
	Average (kPa)		367	674	752
	Cement 315 W/C 58	1	408	951	989
		2	442	960	998
		3	427	941	1014
	Average (kPa)		426	951	1000

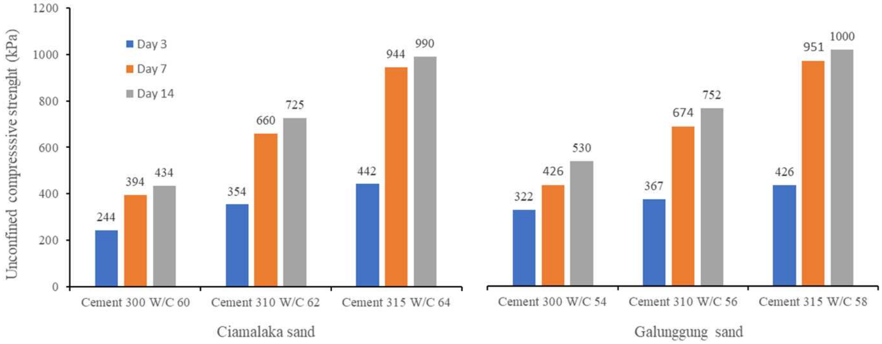

Fig. 3. Comparison of unconfined compression strength between foam concrete compose of Cimalaka sand and Galinggung sand

Fig. 3 presents a bar chart comparison for the two types of sand, Cimalaka and Galunggung, showing that the strength of foam concrete increases with each passing day for all compositions. The composition with 315 kg/m^3 of cement exhibits the highest unconfined compressive strength compared to the other compositions. The graph also indicates that the difference in compressive strength between Cimalaka sand and Galunggung sand is minimal, with Galunggung sand being only 10 kPa higher.

3.5 Modulus elasticity

In the study of the shear and compressive strength characteristics of a material, it is also essential to analyze its deformation characteristics[14]. One way to do this is by examining its elastic modulus[15]. This analysis provides valuable insights into the material's ability to deform under stress and return to its original shape, which is crucial for understanding its overall performance in various applications. The calculation of the elastic modulus of foam mortar uses data obtained from laboratory test results by analyzing the relationship between stress and strain. An example of the calculation of the elastic modulus is presented in Fig. 4. And the calculation results are resumed in Table 5.

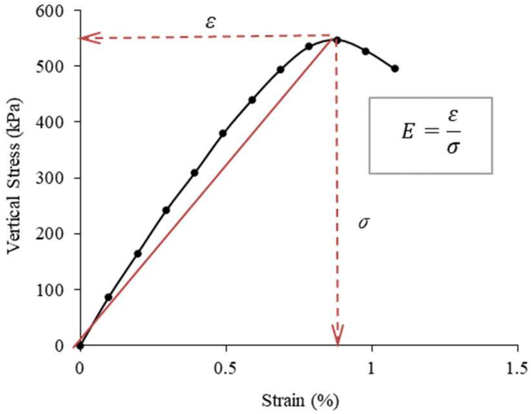

Fig.4 . Typical vertical stress and strain relationship on unconfined compression test for foam concrete in this research and modulus elasticity definition

Table 5. Elastic modulus of foam concrete compose of two types of sand

Types of Sand	Composition	UC Strength kPa	Strain (ε) %	Elastic Modulus MPa
Cimalaka	Cement 300 w/c 60%	434	0,8	0,543
	Cement 310 w/c 62%	724	0,9	0,805
	Cement 315 w/c 64%	990	0,9	1,101
Galunggung	Cement 300 w/c 54%	531	0,9	0,589
	Cement 310 w/c 56%	752	0,9	0,836
	Cement 315 w/c 58%	10	0,9	1,110

The table and figure indicate that the highest elastic modulus value for foam mortar using Mount Galunggung sand is found in composition 3, measuring 1.110 MPa. Similarly, for Cimalaka sand, the highest elastic modulus is also observed in composition 3, with a value of 1.101 MPa. The elastic modulus of foam mortar is significantly influenced by the density of the material. Generally, as the density of the foam mortar increases, the elastic modulus value also rises. This is because denser materials contain fewer pores and more solid components, allowing them to better withstand applied loads

4 Conclusions

The research aims to assess how variations in material composition impact the unconfined compressive strength of foam mortar, while also analyzing the influence of sand type and test age. The conclusions are as follows:

1. Effect of Material Composition on Compressive Strength. The use of Cimalaka and Galunggung sands results in different compressive characteristics of foam concrete. To meet the minimum unconfined compressive strength of 800 kPa, the optimal composition involves the correct ratio of cement, sand, and foam agent. Using Cimalaka sand, a mix ratio of 64% W/C with 6.68 kg cement, 4.284 liters of water, 6.447 kg sand, and 12.427 kg foam agent achieves an average compressive strength of 990 kPa. Using Galunggung sand, a W/C ratio of 58%, with 6.68 kg cement, 3.881 liters of water, 5.683 kg sand, and 13.084 kg foam agent, results in an average compressive strength of 1000 kPa. Both compositions meet the 14-day strength requirements for foam mortar as per the Ministry of PUPR's guidelines for road construction.

2. Effect of Test Object Age on Compressive Strength. The compressive strength increases with the age of the foam mortar samples. Strength is lower at 3 days compared to 7 and 14 days. The composition of Cimalaka and Galunggung sands, particularly with an optimal foam agent ratio, accelerates strength gain in the early stages.

3. Effect of composition on foam concrete modulus. The modulus of elasticity is influenced by the ratio of cement, sand, and foam agent. Compositions with a higher cement ratio yield a stiffer structure and higher elastic modulus. The highest modulus for Cimalaka sand is 1.101 MPa in composition 3. The highest modulus for Galunggung sand is 1.110 MPa in composition 3. Foam concrete with a higher modulus of elasticity is stiffer and better resists deformation under load.

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