MANUFACTURING FOAMED CONCRETE AS AN ALTERNATIVE MATERIAL TO REPLACE EMAS (ENGINEERED MATERIALS ARRESTING SYSTEM)

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ABSTRACT

The Engineered Material Arresting System (EMAS) serves as a solution to overrun aircraft, particularly on runways with Runway End Safety Area (RESA), thereby enhancing aviation safety. This study involves the fabrication and testing of foam concrete using local materials, including cement, fly ash, and foam, both with and without the addition of fibers. The target density is set at 600 kg/m³. Materials utilized include Gresik PCC cement, Paiton fly ash, AKS brand foaming agent for foam production, and polypropylene fibers (Fosroc PPF M12). The research methodology encompasses literature of review and experimentation. The mix composition for one cubic meter of concrete comprises 300 kg cement, 111 kg fly ash, 135 liters water, and 720 liters foam. In the case of foam concrete with fibers, 2 kg of polypropylene fibers are added for 1 m^3 of mix. Test specimens consist of 35 cylindrical specimens measuring 150 mm x 300 mm and 10 plates measuring 400 mm x 300 mm x 83 mm. The test results indicate a foam concrete density of 560 kg/m³ (for foam concrete with polypropylene fibers), slightly below the target of 600 kg/m³. The average compressive strength of specimens without fibers is 1.08 MPa, with a maximum deformation of 13.00 mm. Meanwhile, for foam concrete with fibers, the average compressive strength is 0.53 MPa, with a maximum deformation of 36.50 mm. The inclusion of fibers in foam concrete leads to lower compressive strength but increased ductility, as evidenced by longer deformation. This characteristic makes the addition of polypropylene fibers more suitable for use in EMAS. Consequently, Paiton fly ash, Gresik Portland cement, and foam (AKS foaming agent) can be effectively employed as local materials in the production of foam concrete for EMAS.

Keywords: foam concrete, compressive strength, fly ash, foaming agent, polypropylene fiber

1. INTRODUCTION

Airplane accidents resulting from failure to stop at the end of the runway or slipping beyond it are quite common. The cause of such failures could stem from technical problems with the aircraft or be influenced by extreme weather conditions. To prevent these accidents, the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO) require the existence of a Runway End Safety Area (RESA) with a length of 1000 ft (330 m) at the end of the runway to provide a safe stopping distance for a plane skidding at a speed of 70 knots. Some airports face difficulties in meeting these requirements due to a lack of available land and the high associated costs. For instance, at I Gusti Ngurah Rai International Airport, extending the runway is challenging due to limited space, with a highway to the east and the deep sea to the west.

Runways that do not meet FAA and ICAO standards can be addressed by utilizing a Soft Ground Arrestor System (SGAS). Currently, the only FAA-approved SGAS is the Engineered Materials Arresting System (EMAS). When an aircraft enters EMAS, this SGAS creates an incline transition from the paved runway to the cellular cement arresting bed. The plane's wheels crush the EMAS blocks, generating a resistive load or drag force that rapidly decelerates and eventually halts the aircraft [1].

Research on EMAS is primarily conducted abroad. Implementing this innovation in Indonesia would entail significant costs due to the need to import materials and challenges in managing patent ownership. However, if EMAS could be developed domestically using local materials, it would potentially save the country's foreign exchange. Research on SGAS has been conducted [2] with various compositions of foam concrete mixtures yielding different densities. Test results revealed that a specific mixture composition produces foam concrete suitable for EMAS, with a density of 600 kg/m³. This mixture includes 300 kg cement, 111 kg fly ash, 135 kg water, and 720 l foam. Despite its low compressive strength of 5 MPa, this mixture is suitable for EMAS applications.

In this study, foam concrete was produced similarly to research conducted by Steyn et al. (2014), utilizing local materials such as Gresik PCC cement, fly ash from Paiton, AKS brand foaming agent, and polypropylene fiber (Fosroc PPF M12). The aim was to achieve a density target of 600 kg/m³ and to investigate the effect of fiber on foam concrete.

2. THEORY AND METHODS

2.1 Theory

2.1.1 Soft Ground Arresting System (SGAS)

SGAS is an alternative solution on airport runways where DAULP or RSA do not meet FAA international standards [3].

2.1.2 EMAS (Engineered Materials Arresting Systems)

EMAS, defined as a base of pre-cast blocks, can be constructed from various materials that meet FAA requirements. Positioned at the end of the runway, EMAS serves to decelerate aircraft experiencing overruns [4]. Its effectiveness relies on a material that is easily crushed yet durable. Consequently, incorporating low-density concrete into EMAS designs is feasible.

2.1.3 Foam Concrete

Foamed concrete is a hardened Portland cement paste or mortar with low density, containing numerous small air bubbles known as entrained air [5]. To produce foamed concrete, air is intentionally introduced into the mixture by blending a suitable foaming agent with the appropriate moisture content using a specialized mixer. This process generates foam, which subsequently shapes the structure of the foamed concrete.

2.1.4 Foam Concrete as SGAS

For foamed concrete to qualify as SGAS, it must adhere to the specifications outlined by the FAA in 2012. SGAS materials are required to possess the characteristic of being soft under tire pressure while offering significant resistance [6]. Achieving this entails utilizing materials with low density, low compressive strength, and high energy absorption capabilities [7].

In research conducted by Steyn et al. (2014), the potential utilization of foam concrete as SGAS was assessed. The concrete-making process involved evaluating several mix designs, as detailed in Table 1. Subsequently, the foamed concrete was poured into plates measuring 1.2 x 0.8 x 0.25 m, and plate tests were conducted on concrete samples after 7 days of curing. These measurements utilized a plate size reflective of the relevant vehicle contact diameter. Additionally, cubes and cylinders were cured for one week, followed by compressive strength and stiffness testing after 7 and 28 days.

Table 1. Mix design for one cubic meter for different densities

Density (kg/m^3)	Cement (kg)	Fly ash (kg)	Water (l)	Foam (l)

1200	300	616	256	374
1000	300	448	216	489
800	300	280	175	604
600	300	111	135	720

From the results of his research it was concluded that densities of 600 kg/m³ and 800 kg/m³ allow greater settlement and the stress or deformation relationships are very similar to the materials currently used in arrester beds.

2.1.5 Portland Cement

Portland cement is a hydraulic cement produced by grinding clinker which mainly consists of hydraulic calcium silicates with gypsum as an additional ingredient. The silicate and aluminum content in cement is the main element that forms cement which, when it reacts with water, becomes an adhesive medium.

2.1.6 Water

Water is needed in making concrete so that a chemical reaction occurs with the cement. In general, drinking water can be used to mix concrete. Because the characteristics of cement paste are the result of a chemical reaction between cement and water, it is not the ratio of water to the total material that determines, but only the ratio between water and cement in the mixture that determines.

2.1.7 Additional Ingredients (Admixture)

Admixture are defined in the Standard Definition of Terminology Relating to Concrete and Concrete Aggregates [8] and in Cement and Concrete Terminology (ACI SP-19) as materials other than water, aggregates and hydraulic cement that are mixed in concrete or mortar which is added to modify the properties and characteristics of the concrete, for example to make work easier, save money, or for other purposes such as saving energy. In this research, the mineral additives used were fly ash and the chemical additives used were foaming agents and polypropylene fibers.

2.1.7.1 Fly Ash

According to [9] fly ash is defined as fine grains resulting from the residue of burning coal or coal powder [10]. The main components of coal fly ash are silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), calcium (CaO), potassium, sodium, titanium, and small amounts of sulfur [11]. In this research, the fly ash used came from PLTU Paiton, Probolinggo, East Java.

2.1.7.2 Foaming Agents

Foaming agents are chemicals derived from a mixture of natural and artificial ingredients. These agents are formulated from concentrated solutions of surfactant materials, which need to be dissolved in water for use. Synthetic-based foaming agents typically have a density of around 40 kg/m³ and can expand approximately 25 times their original volume. This type of foam agent exhibits excellent stability for bricks with a density exceeding 1000 kg/m³. The concentration ratio of the foam agent can vary from 1:33 to 1:39, meaning, for instance, 1 liter of Noraite PA-1 mixed with 39 liters of water yields 40 liters of foam agent. Consequently, 40 liters of foam agent can expand to about 500 liters of stable foam with a weight of approximately 80 kg/m³.

2.1.8 Polypropylene Fiber

Polypropylene fiber is a fundamental material commonly employed in the production of plastic-based materials. Initially utilized in the textile industry due to its affordability and ability to yield high-quality products, this material is in the form of filaments that break down when mixed into concrete mixtures. Such fibers can enhance the flexural and compressive tensile strength of concrete, mitigate cracks caused by shrinkage, bolster resistance to impact, and augment ductility [12]. The Fosroc brand polypropylene fiber utilized in the research is Fosroc PPF M12. Fosroc PPF comprises 100% polypropylene material with a high fiber content devoid of olefins, developed as a crack control additive for cement materials. Fosroc PPF M12 serves to inhibit the formation of small cracks due to premature drying and temperature fluctuations, while also harnessing the inherent properties of hard materials for optimal utilization.

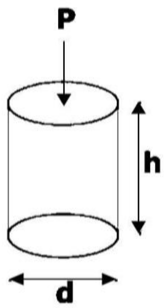
2.1.9 Density of Foam Concrete

The greater the percentage of foam agent added to the concrete, the lower the density value will be [13]. This is caused by bubbles forming inside the foam concrete. The volume of foam concrete filled with air causes the density of the foam concrete to decrease. The reaction process between fly ash and cement makes the aggregate grains in foam concrete denser.

2.1.10 Compressive Strength of Concrete

Compressive strength of the concrete is the amount of load per unit area that causes the concrete specimen to crumble when it is loaded with a certain compressive force, which is produced by a pressing machine (SNI 03-1974-1990). Concrete compressive strength can be calculated using the following equation:

$$f'c = \frac{P}{A} \tag{2.1}$$



Informations:
$f'c$: Concrete Compressive strength (Mpa)
P : Compressive load (N)
A : Cross-sectional area of the test object (mm^2)

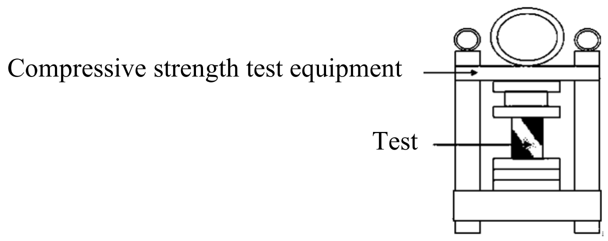


Figure 1. Concrete compressive strength test

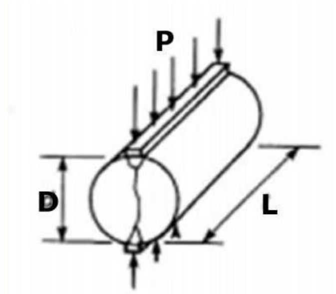
2.1.11 Uniaxial Compressive Strength (UCS)

Compressive strength UCS (Unconfined Compression Strength Test) also known as unconfined compressive strength (qu), is a general strength parameter that is often used to measure strength in rocks. This is determined through a uniaxial compressive strength test, also known as an unconfined compressive strength test. A uniform vertical normal stress is applied to the horizontal circular cross section of the cylindrical sample. During loading, there are no pressure constraints around the sample and the test is quite simple and the interpretation is straightforward. Vertical stress when it reaches failure is uniaxial compressive strength or unlimited compressive strength, denoted by qu or σc [14].

2.1.12 Split Tensile Strength

Concrete split tensile strength refers to the indirect tensile strength value of a cylindrical concrete sample. This value is obtained by testing concrete samples placed horizontally parallel to the surface of the compression testing machine's pressing table, following the SNI 03-2491-2002 standard. When the load P reaches its peak, the cylindrical or cubic concrete sample being tested will crack or break. The split tensile strength can be calculated using the following equation:

$$f = \frac{2\,P}{\pi\,L\,D} \tag{2.2}$$



Informations:
f : Tensile strength (kg/cm^3)
P : Maximum test load (kg)
L : Length of the test object (cm)
D : diameter or width of the test object (cm)

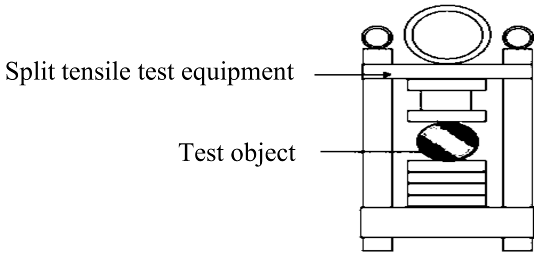
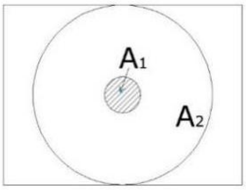


Figure 2. Testing of concrete splitting tensile strength

2.1.13 Plate Test (Footing)

The theory and loading of this plate uses bearing strength referring to SNI 2847 of 2019 [15]. For the surface of the support area which is wider on all sides than the loaded area, the nominal support strength (B_n) is calculated using the following equation:

$$B_n = 2\,(0{,}85\,f'c\,A_1) \tag{2.3}$$



Informations:
B_n : Nominal bearing strength (N)
$f'c$: Concrete Compressive strength (Mpa)
A_1 : Area covered (mm²)
A_2 : Cross-sectional area of the test object (mm²)

Figure 3. Testing the support strength of concrete slabs

2.2 METHODS

2.2.1 Research Variables

The method used in this research is a literature study and experiment with the dependent variables being density values, cylinder compressive strength, cylinder split tensile strength, and plate support strength. Meanwhile, the independent variables in this research are variations in the mixture of fly ash, water, foam agent and polypropylene fiber.

2.2.2 Material Composition and test objects

In this research, foam concrete was made with two different mixtures as in Table 2.

Table 2. Composition of foam concrete mixtures

Mixture	Cement (kg/m$^{3)}$	*Fly ash* (kg/m^3)	Water(l/m^3)	*Foam* (l/m^3)	Polypropylene fiber (kg/m^3)
Mixture I	300	195	155	662	2
Mixture II	300	111	135	720	2

The number of test objects made for mixture I was 1 cylinder without fiber and 5 cylinders with fiber. Meanwhile, the test objects made for mixture II were 14 cylinders without fiber, 15 cylinders with fiber, 6 plates without fiber, and 4 plates with fiber.

2.2.3 Making and Testing Test Objects

The materials for creating test objects are mixed using the prefoaming method, wherein the basic mixture consisting of cement, fly ash, and water is stirred separately from the foam mixture. Once the base mixture and foam mixture are combined and polypropylene fibers are dispersed into the mixture in the mixer, the foam concrete is poured into molds for test specimens. These molds include cylindrical specimens measuring 15 cm x 30 cm and plate boxes measuring 40 cm x 30 cm with a thickness of 0.83 cm. After one week of treatment, the cylindrical and plate specimens undergo compressive strength testing, split tensile testing, and support strength testing at both 7 days and 28 days.

2.2.4 Research Location and Time

The research was conducted at the Structure and Materials Laboratory of the Civil Engineering Study Program, Faculty of Engineering, Udayana University.

3. RESULTS AND DISCUSSION

3.1 Testing Foam Concrete Density in Phase I Mixtures

The density of foam concrete obtained from the mixture without fiber and with fiber in the first mixture (trial mixture) can be seen in Table 3.

Table 3. Density of foam concrete mixed cylindrical test specimens I

Code	No Fiber		Code	With Fiber	
	Weight (gram)	Density (kg/m^3)		Weight (gram)	Density (kg/m^3)
For split tensile testing, the test object is 7 days old					
BBSCK-1	3,497.00	659.97	-	-	-
-	-	-	BBSCK-2	3,668.6	692.35
For compression testing, the test object is 28 days old					
-	-	-	BBSCK-3	3,856.70	727.85
-	-	-	BBSCK-4	4,712.20	889.30
-	-	-	BBSCK-5	3,605.10	680.37
-	-	-	BBSCK-6	6,705.00	1,265.39

Note: cylindrical test object 15 cm x 30 cm with a volume of 5,298,750.00 mm^3.

In Table 3, it is evident that the density values obtained by the test specimens in the mixture during stage I are not evenly distributed. This discrepancy arises because the pouring of foam concrete into each mold is conducted while the concrete mixer is continuously running, causing the foam concrete mixture remaining in the mixer to lose foam, resulting in increased density. To achieve a more uniform density value, the tests will be conducted again using the mixture in stage II.

3.2 Testing Foam Concrete Density in Phase II Mixture

Referring to the technical error observed during the pouring of foam concrete in the stage I mixture, in the stage II mixture, the pouring of foam concrete into each mold was conducted after turning off the concrete mixer, and the foam concrete in the mixer was then poured into the molds.

Based on the test results, the highest foam concrete density recorded was 495 kg/m^3 for foam concrete without fiber and 560 kg/m^3 for foam concrete with fiber, slightly below the target of 600 kg/m^3.

3.3 Max. Force and Max. Compressive Strenght Test Objects of Cylinders and Foam Concrete Plates in Phase II Mixture Aged 28 Days

Max. force, Max. compressive strength, and Max. The tensile strength of each foam concrete specimen without fiber and with fiber for the cylindrical specimen can be seen in Table 4.

Table 4. Max. force, Max. compressive strength, and Max. tensile strength of cylindrical test specimens aged 28 days

Code	Compressive Testing		Code	Split Tensile Testing	
	Max. force (N)	*Max. compressive strength* (MPa)		*Max. force* (N)	*Max. tensile strength* (MPa)
Without fiber, the test object was 28 days old					
TTS128	18,488	1.05	TBTS128	16,668	0.24
TTS328	19,922	1.13	TBTS228	18,130	0.26

TTS428	18,967	1.07	TBTS328	11,306	0.16
With test specimen fiber aged 28 days					
TDS128	10,031	0.57	TBDS128	13,710	0.19
TDS328	11,517	0.65	TBDS228	11,212	0.16
TDS528	6,370	0.36	TBDS328	9,634	0.14

Note: The cylindrical specimen measures 15 cm x 30 cm and has a surface area of 17,663 mm^2 for compression specimens and 45,000 mm^2 for split tensile specimens.

The average compressive and split tensile strength values for foam concrete without fiber are 1.08 and 0.22 MPa, respectively, while the average compressive and split tensile strength values for foam concrete with fiber are 0.53 and 0.16 MPa, respectively. Table 4 illustrates that the average values of compressive strength and split tensile strength at 28 days for cylindrical specimens without fiber exceed those for cylindrical specimens with fiber. The ratio of the difference in strength between foam concrete with fiber and foam concrete without fiber is approximately 1:3 for compressive strength and 1:4 for split tensile strength.

Max. force and support strength of each foam concrete specimen without fiber and with fiber for the plate specimen can be seen in Table 5.

Table 5. Max. force and plate support strength of 28 day plate test specimens

Code	No Fiber		Code	With Fiber	
	Max. force (N)	Strong plate support (MPa)		*Max. force* (N)	Strong plate support (MPa)
The test object was 28 days old with a surface area of 12,468.981 mm^2					
PLTS128	16,758	1.34	PLDS128	4,312	0.35
PLTS228	15,573	1.25	PLDS228	9,796	0.79
PLTS328	16,089	1.29	-	-	-

Note: The plate test object measures 40 cm x 30 cm x 8.3 cm with a test object diameter of Ø 12.6 cm.

The average support strength value for plates without fibers is 1.3 Mpa, while the average support strength value for plates with fibers is 0.57 Mpa. Table 5 shows that the average value of the bearing strength of concrete slabs aged 28 days for plate specimens without fiber is greater than for plate specimens with fiber.

3.4 Comparison of Deformation in Graphs of Foam Concrete Without Fibers and With Fibers in Phase II Mixtures

Figure 5 shows the maximum deformation (d_{max}) of 13 mm in foam concrete without TTS328 fiber with P_{max} 19,922 N, while in Figure 6 the maximum deformation (d_{max}) in foam concrete with TDS328 fiber is 36.5 mm with P_{max} 11,517 N.

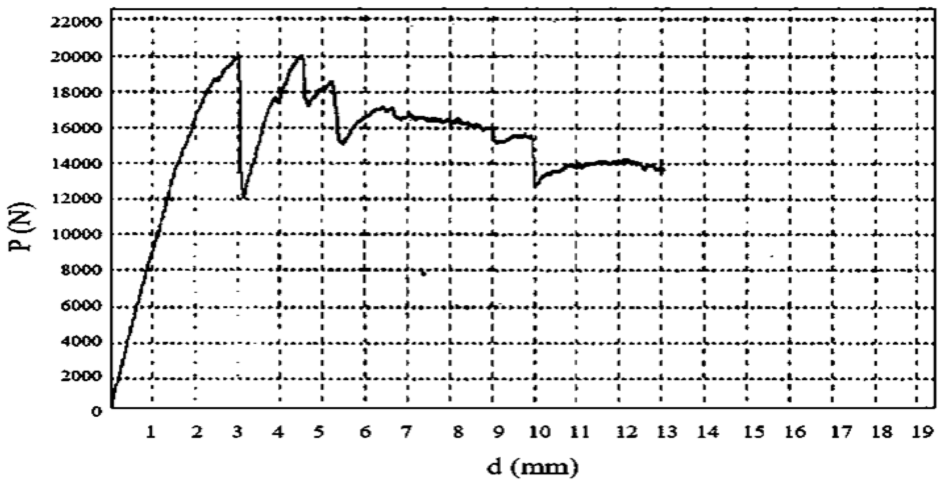


Figure 5. Deformation graph of TTS328 fiberless cylinder (28 days) with d 4.30 mm at P_{max} 19,922 N and d_{max} 13 mm at P 13,750 N

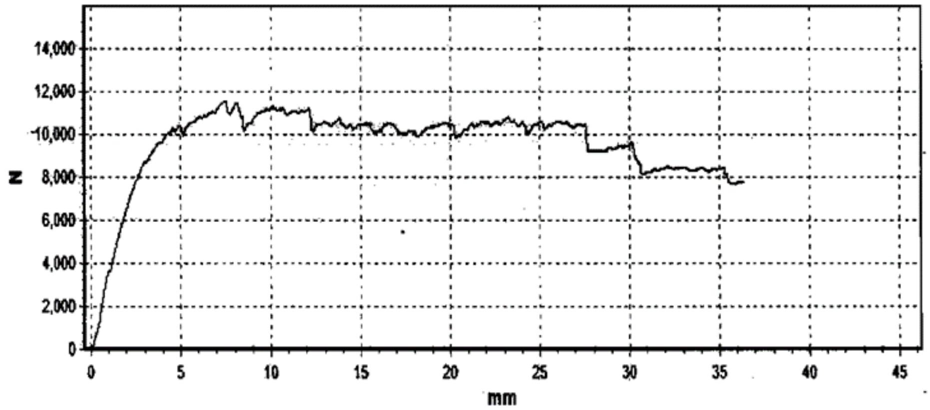


Figure 6. Cylinder compression graph with TDS328 fiber (28 days) with P_{max} 11,517 N at d 6.75 mm and d_{max} 36.5 mm at P 7,900 N

The maximum deformation value (d_{max}) of 36.5 mm in foam concrete with fiber compared to the maximum deformation value (d_{max}) of 13 mm in foam concrete without fiber shows that foam concrete with fiber has a longer deformation value, so the concrete foam with more ductile fibers.

4. CONCLUSIONS

In this research, foam concrete was produced using local materials including Gresik PCC cement, fly ash from Paiton, AKS brand foaming agent, and polypropylene fiber (Fosroc PPF M12), following the methodology outlined in previous research by Steyn et al. (2014). The mixture process involved two stages, with compositions per one cubic meter as follows: the stage I mixture comprised 300 kg of cement, 195 kg of fly ash, 155 liters of water, 662 liters of foam, and 2 kg of polypropylene fiber, while the stage II mixture consisted of 300 kg of cement, 111 kg of fly ash, 135 liters of water, 720 liters of foam, and 2 kg of polypropylene fiber. The research utilized a total of 15 cylinders without fiber, 20 cylinders with fiber, 6 plates without fiber, and 4 plates with fiber for testing purposes. Tests were conducted at both 7 days and 28 days of age. Based on the results of the tests and discussions conducted, the following conclusions can be drawn:

1. (a) The highest foam concrete density was 495 kg/m³ for foam concrete without fiber and 560 kg/m³ for foam concrete with fiber, slightly below the target of 600 kg/m³. The average compressive and tensile strength values for foam concrete without fiber are 1.08 and 0.22 Mpa respectively with a maximum deformation of 13.00 mm. The average compressive and tensile strength values for foam concrete with fiber are 0.53 and 0.16 Mpa respectively with a maximum deformation of 36.50 mm. The average bearing strength value for plates without fibers is 1.3 Mpa, while the average support strength value for plates with fibers is 0.57 Mpa, so this foam concrete can be used as a EMAS material.
   (b) The density of foam concrete depends on the mixing duration, the longer the mixing process causes the air bubbles or air cavities in the foam concrete to decrease, so that the foam concrete became heavier (high density).

2. Using fiber in foam concrete increase the density of foam concrete, because fiber adds mass to the mixture. Fibers in foam concrete produce lower compressive strength but longer deformation, thus the addition of polypropylene fibers makes it more ductile which is better used as EMAS.

5. SUGGESTIONS

1. Further research is needed to find the correct mixing duration of foam concrete to obtain the desired density.

2. In relation to the application of foam concrete as EMAS, it is necessary to carry out numerical research using laboratory research data before field testing is carried out.

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