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Submission date: 21-Oct-2022 12:29PM (UTC+0700)
Submission ID: 1931295857
File name: 5.0096707-sahir.pdf (615.7K)
Word count: 3122
Character count: 15575

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Cite as: AIP Conference Proceedings **2453**, 020026 (2022); https://doi.org/10.1063/5.0096707
Published Online: 25 July 2022

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Physical Behavior of Foam Concrete Constructed with Blended Cement and Polyolefin Fiber

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Abstract. The ratio of the amount of water to cement (w/C) serves as the main factor that regulates the physical behavior of a cement-based material mixture, therefore two different foam concrete design mixes were prepared in this research. The physical behaviors of foam concrete related to both freshly mixed foam concrete and hardened foam concrete were studied, indicating a stable foam to be blended with the mortar-based cement of Portland composite cement and Polyolefin Fiber, resulting in fresh foam concrete flowing uniformly. Likewise, the results of compaction indicated that the fresh foam concrete was capable of properly compacting in the cylinder mold without the help of vibration efforts, in which higher number of w/C caused the bigger flow in diameter of fresh foam concrete compared to the mix with lower w/C. In sum, foam concrete with lower w/C presented higher compressive strength and modulus of elasticity.

INTRODUCTION

Over the a past century, concrete becomes a popular material with numerous and widespread use in for manufacturing purposes, requiring a simple method to achieve the planned strength, where Ordinary Portland cement (OPC) becomes the main constituent material of concrete. A number of efforts and studies have been conducted to reduce the use of virgin material in the manufacture of OPC. One of the efforts is conducted to craft a more efficient cement-based binder in the use of by-products containing an appropriate amount of amorphous silica such as fly ash. Fly ash is a by-product generally obtained from power plants that use coal as fuel. In addition, the use of fly ash as part of the blended cement causes a reduction in fly ash disposed in the pond, along with the reduction in the use of virgin material such as clay as a source of silica increases efforts to conserve the environment, thereby reducing the fuel consumption in the cement production [1-2]. A study reports that mortar with reliable performance could be prepared by applying the blended cement [3]. Similarly, the blended cement of PCC serves as a constituent material of concrete in accordance with the technical requirements for civil buildings [4-5].

Portland cement-based foam concrete is made from mixture of stable foam with cement paste or mortar containing sand. Hardened foam concrete is classified as lightweight concrete, in which proper volume of entrained micro air voids are produced by the stable foam made with appropriate volume of foam agent with water. High flowability, hence could be compacted with own weight without the use of vibrator, minimum consumption of coarse aggregate, light density of 800-1900 kg/m^3, controlled low strength, and favorable thermal insulation properties, which present beneficial physical properties of foam concrete as lightweight concrete [6-7]. This research is part of an intensive effort to develop the manufacture of foam concrete employing Portland composite cement for widespread utilization.

Various types of fibers were previously developed to improve the performance of cement-based materials for building construction. One type of fiber which has recently been developed with a stick-like shape, such as a Polyolefin Polymer based fiber. One of the objectives of this research is to develop the use of Polyolefin Polymer based fibers as constituents that form foam concrete. It is thus acknowledged that at the constant amount of cement in a mixture, increasing the amount of water further affecting physical behavior in terms of freshly mixed and hardened cement-based materials, such as: paste, mortar and concrete [8]. This study prepared the two different water and cement ratios (w/C) to produce foam concrete mixtures.

This study prepared foam concrete made of blended cement-based mortar, foam and Polyolefin Polymer fiber with two different w/C mixtures. In this research, the behaviors of fresh foam concrete and hardened foam concrete were studied experimentally through a series of tests. Behaviors related to fresh mixed foam concrete included flowability and resistance to segregation between mortar and foam. The behavior related to hardened concrete was studied by using compressive load strength test. During the compressive strength test, a number of measurement devices was prepared, captured and monitored to obtain compressive load and deflection of specimens to obtain the compressive strength and modulus of elasticity of hardened foam concrete.

1st International Conference on Technology, Informatics, and Engineering
AIP Conf. Proc. 2453, 020026-1–020026-6; https://doi.org/10.1063/5.0096707
Published by AIP Publishing. 978-0-7354-4356-3/$30.00

MATERIALS AND EXPERIMENTAL METHODS

Mortar Based Blended Cement

Mortar in this study was prepared from blended cement and river sand. Blended cement, such as PCC has been used in construction works extensively in Indonesia This blended cement is produced based on the national standard for Portland composite cement [9]. River sand employed as fine aggregate in this study was obtained from Jeneberang River, located in Gowa Regency, South Sulawesi Province. Sand has absorption and specific gravity (in surface saturated dry) of 2.5% and 2.45%, respectively.

Polyolefin Polymer Based Fiber

Table 1 indicates the physical properties and image of the Polyolefin Polymer utilized in this study.

TABLE 1. Physical Properties of Polyolefin Polymer based Fiber

Property	Value	Image
Density	0.92 g/cm3	
Fiber length	48 mm	
Mean Width	1.37 mm	
Mean Thickness	0.34 mm	
Melting point	170°C	
Water absorption	Nil	
Tensile strength	550 Mpa	

Production of Foam Concrete and Fresh Foam Concrete Test

The two materials are mixed with different w/C, prepared in this research. The first and second mixes have w/C of 49.21 % and 38.55 %, respectively. Table 2 indicates Mix 1 and Mix 2.

TABLE 2. Mix Design of Foam Concrete with different w/C

Material	Specific Gravity	Mix design 1 (w/C=49.21%)	Mix design 2 (w/C=38.55%)
Water (kg)	1	267.61	209.64
Blended Cement (kg)	3.02	543.82	543.82
Fine Aggregate (kg)	2.48	1054.28	1198.05
Macro Synthetic Fiber (kg)	0.92	5.44	5.44
Total (kg)		1871.16	1956.95
Fresh Foam Concrete Density (kg/m^3)		1375.00	1460.00
Mortar Portion (%)		73.48%	74.61%
Foam Portion (%)		26.52%	25.39%
Foam Agent to Water Ratio		3:10	3:10

As previously mentioned, foam concrete is constructed of mortar and stable foam. Thus, that the manufacture of mortar and foam were simultaneously conducted with blended cement of PCC based mortar was prepared in a mixer. Further, the stable foam prepared separately was added to the mixer filled with fresh mortar. Mixing fresh mortar with foam was conducted until obtaining stable fresh foam concrete.

Before pouring into cylindrical mold with diameter of 100 mm and height of 200 mm, flowability test on freshly mixed foam concrete was conducted by using Abrams cone. Fresh foam concrete was later poured into the cone without tamped with a tamping rod. After the cone was lifted, the flow diameter was measured to study the flowability of fresh concrete.

Fresh foam concrete was poured into the mold without the aid of compaction using tamping rod and vibrating activities to solidify it in the mold. Furthermore, visual observations were conducted for several hours to evaluate the resistance of fresh concrete located in the separation between foam and mortar or sand.

Foam concrete in the mold is later stored in a room with a temperature of 28 ± 2.5°C and humidity of 70 ± 10%. After 24 hours, hardened foam concrete was removed from the mold and stored in the laboratory room with temperature of and humidity the day of the test.

Compressive Strength Testing and Strain Measurement

Figure 1 indicates the usage of devices to test the compressive strength of cylindrical specimen. Compressive strength was obtained by placing a load cell to capture compressive load in the Universal Testing and Machine UTM, where the compressive stress is the monotonic compressive load divided by the area of the specimen.

FIGURE 1. Compressive Strength Test and Computer Set

The compressive test is conducted at a speed of 0.5 mm/min until the specimen experienced compressive destruction. Compressive strength contains the maximum stress obtained from the cylindrical specimen. The strain that occurred during compressive loading was obtained through two LVDTs that were vertically amounted in the direction of the compressive load. The average displacement value of the two LVDTs divided by the height of the specimen became the strain value. All loading and displacement values were monitored and recorded with a set of data acquisition device. The value of modulus of elasticity was obtained based on the relationship between compressive stress with strain of each specimen. The following Equation 1 is utilized to obtain the Modulus of Elasticity value.

$$E_c = \frac{S_2 - S_1}{\varepsilon_l - 0.00005} \tag{1}$$

In which:
E_c: chord modulus of elasticity (MPa)
S_2: stress corresponding to 40% of ultimate load (MPa)
S_1: stress corresponding to a longitudinal strain ε_1 (MPa)
and ε_1: longitudinal strain produced by stress S_2

RESULTS AND DISCUSSION

Flowability of Fresh Foam Concrete

Figure 2 indicates flowability of fresh foam concrete obtained from mixture 1 and mixture 2, respectively, indicating that higher amount of water causes mix 1 to flow more widely in all directions reaching an average diameter of 70 cm. Meanwhile, the lower amount of water in mixture 2 resulted in fresh foam concrete having an average flow diameter of 45 cm. The addition of 12% water resulting in mix 1 having a diameter 55.56% was greater than the flow diameter of the mix 2. Proper Visual investigation indicates that the two mixes made of blended cement-based paste and foam, were able to bind sand and fibers, thereby enabling the fresh condition the foam concrete to flow with its own weight to all directions, without segregation between the paste and sand or fiber, indicating no visible blended. Therefore, these results indicate that the stable foam can blend with the paste cement resulting fresh foam concrete with adequate flowability. The volume weight of mix 1 was 1375 kg/m^3 and the volume weight of mix 2 was 1460 kg /m^3, respectively.

(a) Mix 1 (w/C 49.21%) (b) Mix 2 (w/C 38.55%)

FIGURE 2. Flowability of fresh foam concrete

Setting Process

After fresh foam concrete was poured into the mold, visual observation was conducted up to several hours of setting process. It can be seen that there was no bleeding on the upper surface of the all specimens and there was no segregation between mortar, fiber and foam. Stable mixture made of foam, blended cement-based mortar and fiber could be achieved, hence for all mix, the setting process went well resulting the hardened foam concrete formed in the mold.

Shape and Exterior Appearance of Hardened Foam Concrete

In an effort to determine the results of compaction, visual observation of the shape and exterior appearance of each specimen is conducted in detail prior to the compressive strength test. For all mix, visual observation results indicate that fresh foam concrete that poured into the mold could flow by its own weight to adequately fill all the spaces up to the corners of the mold; hence, the external appearance of the hardened foam concrete confirms that there are no honeycombs or large holes due to the air bubbles left by the unmixed water with cement paste.

Compressive Strength of Foam Concrete

Table 3 summarizes the combined effect of fiber and blended cement-based mortar on the development of compressive strength of foam concrete from seven days to twenty-eight days. Mix 1 specimens had compressive strength of 1.54 MPa and 2.63 MPa at the age of 7 and 28 days, respectively. In addition, there was an increase in a compressive strength by 70.52% from the concrete age of seven to twenty-eight days, in which the mix 2 specimens had compressive strength of 2.62 MPa and 4.15 MPa, respectively. There was an increase in compressive strength by 58.59% from the age of seven to twenty-eight days. The increase in compressive strength indicated that the hydration process occurred adequately, thereby binding the cement paste, further reinforcing sand and fiber.

At 7 and 28 days, the mix 2 specimens had higher compressive strength of 69.73% and 57.86%, respectively, as compared to the mix 1 specimens. More amount of water will produce more pores in the hardened foam concrete, hence the compressive strength of the mix 1 specimens was lower than mix 2 specimens.

TABLE 3. Development of Compressive Strength of Foam Concrete

Mix	Age (days)	Compressive Strength (MPa)	Strain at peak stress (mm/mm)
1	7	1.55	0.00296
		1.50	0.00333
		1.58	0.00261
	Average	1.54	0.00297

Mix	Age (days)	Compressive Strength (MPa)	Strain at peak stress (mm/mm)
		2.65	0.00376
	28	2.72	0.00339
		2.52	0.00307
	Average	2.63	0.00340
		2.73	0.00236
	7	2.52	0.00243
		2.60	0.00244
2	Average	2.62	0.00241
		4.22	0.00209
	28	4.07	0.00205
		4.17	0.00201
	Average	4.15	0.00205

MODULUS OF ELASTICITY

Table 4 summarizes the combined effect of fiber and blended cement-based mortar on the development of Modulus of Elasticity of foam concrete from seven days to twenty-eight days.

TABLE 4. Modulus of Elasticity

Variations	Age specimens (days)	Compressive strength (MPa)	S_1 (MPa)	S_2 (MPa)	ε_2 (mm/mm)	Modulus of Elasticity (MPa)
		1.55	0.017	0.62	0.00183	338.80
	7	1.50	0.023	0.60	0.00133	452.33
		1.58	0.030	0.63	0.00104	606.15
Mix 1	Average	1.54	0.023	0.62	0.00140	465.76
		2.65	0.037	1.06	0.00142	748.51
	28	2.72	0.043	1.08	0.00128	853.12
		2.52	0.044	1.00	0.00114	887.39
	Average	2.62	0.041	1.05	0.00128	824.59
		2.73	0.075	1.10	0.00117	907.68
	7	2.52	0.105	1.01	0.00123	821.17
		2.60	0.031	1.04	0.00168	620.24
	Average	2.62	0.211	1.05	0.00075	783.03
Mix 2		4.22	0.110	1.67	0.00077	2193.33
	28	4.07	0.107	1.61	0.00076	2140.89
		4.17	0.113	1.65	0.00074	2254.42
	Average	4.15	0.110	1.64	0.00076	2195.69

Mix 1 specimens presented Modulus of Elasticity of 465.76 MPa and 824.59 MPa at the concrete age of 7 and 28 days , respectively. There was an increase in Modulus of Elasticity by 77.04% from the age of seven to twenty-eight days. At the age of 7 and 28 days, the mix 2 specimens indicated Modulus of Elasticity of 783.03 MPa and 2195.69 MPa, respectively, thereby increasing Modulus of Elasticity by 180.41% from the concrete age of seven to twenty-eight days. The increase in Modulus of Elasticity demonstrated that the hydration process adequately occurred, thus the binding between the cement paste with sand and fiber was getting stronger. At 7 and 28 days, the mix 2 specimens had higher Modulus of Elasticity of 68.12% and 166.28%, respectively, as compared to the mix 1 specimens.

CONCLUSIONS

1. Design of Mix1 for foam concrete with w/C 49.21% and mix design 2 of produced foam concrete with w/C 38.55% generating fresh foam concrete with flow diameters of 700 mm and 450 mm, respectively.

2. Design of Mix1 for foam concrete with w/C 49.21% and mix design 2 of produced foam concrete with w/C 38.55% generating hardened foam concrete with compressive strength of 1.54 MPa and 2.62 MPa at the age of 7 days, and compressive strength of 2.62 MPa and 4.15 MPa at the concrete age of 28 days, respectively.
3. Design of Mix1 for foam concrete with w/C 49.21% and mix design 2 of produced foam concrete with w/C 38.55% generating hardened foam concrete with Modulus of Elasticity of 465.76 MPa and 783 MPa on 7 days, and 824.59 MPa and 2195.69 MPa at the concrete age of 28 days, respectively.

ACKNOWLEDGMENTS

This study was conducted in the Eco-Materials and Concrete Laboratory, Department of Civil Engineering, Faculty of Engineering, Universitas Hasanuddin, Makassar, Indonesia.

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