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Early Age of Volume Weight, Indirect Tensile Strength and Tensile Elastic Modulus of Foam Concrete Containing Blended Cement

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Early Age of Volume Weight, Indirect Tensile Strength and Tensile Elastic Modulus of Foam Concrete Containing Blended Cement

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Abstract. Portland composite cement is a type of blended cement produced by the Indonesian cement factories where fly ash as one of the ingredient and the production is based on efforts to reduce CO_2 emissions in the cement production process. This research is part of the sustainability infrastructure development which is carried out through the use of Portland composite cement as a cementitious material in the manufacture of foam concrete. The purpose of this paper was to contribute to the understanding of the early age volume weight, indirect tensile strength and tensile elastic modulus of the hardened foam concrete. In this study, two mix designs of foam to mortar ratio of 32.53%: 67.47% and 55.41%: 44.59%, by volume were used to produce foam concrete. The test results showed a good compatibility of Portland composite cement-superplasticizer based mortar in combination with foam can be achieved to determine the foam concrete slurry stability and can thus form hardened foam concrete. By using foam to mortar ratio of 32.53%: 67.47%, volume weight, indirect tensile strength and tensile elastic modulus achieved were 1508.3 kg/m^3, 0.83 MPa and 207.5 MPa at three days, and 1476.9 kg/m^3, 0.89 MPa and 254.3 MPa at 7 days, respectively. Tensile strength of foam concrete with foam content of 55.41%: 44.59% at 3 days and 7 days were 0.37 MPa and 0.46 MPa, respectively. The foam to mortar rasio of 55.41%: 44.59% produced foam concrete with tensile elastic modulus of 137 MPa and 200 MPa, at 3 days and 7 days respectively.

1. Introduction

In the last decades, sustainability is a major parameter in the technology development including the construction industry. In this regard, sustainability-based innovation in the production of cement, which is one of the most widely used materials in construction using concrete, continues to be carried out. By producing blended cement that allows the use of by products with contain large amounts of silica, it supports the reduction of CO_2 emissions, reduces the extraction of natural materials and reduces fuel consumption [1]. Fly ash is a by-product that contains large amounts of silica (SiO_2) and a number of materials that can be used as an ingredient in cement. In Indonesia, one of the blended cements that have been produced by national cement factories is Portland composite cement which contains fly ash from burning coal in power plants. Portland composite cement is produced based on

Indonesian National Standard [2]. Many studies have shown that Portland composite cement is able to produce concrete with good performance [3-7].

The use of lightweight materials in the tall building structures and the dwelling houses is part of continuous innovation based on sustainability. Lightweight materials usage can reduce the weight of the load borne by the structural elements so as to lessen the dimension of beam, column and foundation which have implications for reducing material use. Fuel consumption can be reduced on transport of precast lightweight element structures. One of the lightweight materials that continuously have been developed today is foam concrete. Foam concrete is made up of Portland cement based paste, filler or fine aggregate, water and foam without coarse aggregates. The foam content produces numerous microvoids in the hardened foam concrete hence the weight is lighter than the normal weight concrete, while in fresh state the foam concrete slurry has good consistency to flow freely with its own weight filling the mold [8-9]. Preliminary research on the use of Portland composite cement in the manufacture of foam concrete that has been performed by Tjaronge et al shows that the hardened foam concrete made of Portland composite cement has the same early compressive strength as foam concrete made from Ordinary Portland cement [10].

The ability to spread into the mold and self-compacted ability of foam concrete slurry can be evaluated by observing the shape and volume weight of the hardened foam concrete. The amount of foam content affects the volume weight while the volume weight of the hardened foam concrete is related to many physical properties including tensile strength and tensile modulus elasticity. One part of this research was to examine the effect of foam content on the early age volume weight of the hardened foam concrete. Knowledge of the 3 and 7 days volume weigth can be used to measure the load that will be created by 3 days and 7 days age lightweight foam panel if installed on the building structure or the dwelling house.

Solid materials such as rock consists of non-homogeneous compounds and containing numerous microcracks, consequently, the tensile and compression conditions will be responded differently hence there are two types of elastic modules: the compressive elastic module Ec and the tensile elastic modulus (Es). Much effort and attention have been placed on the tensile elastic modulus by researchers, where method to obtain tensile elastic modulus by using indirect tensile strength test (the Brazilian disc) has been systematically developed [11-12]. The hardened foam concrete which the ingredients are not homogeneous, and contains numerous microvoid so has physical similarities to the rocks. Indirect tensile strength and tensile elastic modulus at early age are important parameters with need to be studied in pursue to understand the bearing capacity of the hardened foam concrete to respond the tensile loads. Efforts to obtain indirect tensile strength and tensile elastic modulus of hardened foam concrete by using indirect tensile strength test with equipped with linear variable differential transformers (LVDTs) was reported in this study.

2. Materials and Methods

2.1. Portland Composite Cement

Table 1 displays the physical properties of Portland composite cement used in this study. The chemical compounds of Portland Composite Cement were obtained from X-ray fluorescence (XRF) test results. Chemical compound of the Portland composite cement used as cementitious material is dominated by the CaO and silica (SiO_2) elements, which are 61.79% and 18.39%. Whereas the other composed elements are 0.99% MgO, 1.81% SO_3, 5.15% Al_2O_3, 5.15% Fe_2O_3, and 4.61% LOI (Loss of Ignation), respectively.

Table 1. Physical Properties of Portland Composite Cement

Physical properties	Results
Fineness	382
Compressive strength	
a. 3 days	18.86 MPa
b. 7 days	26.81 MPa
c. 28 days	41.79 MPa
a. Setting time (Vicat test)	
b. Initial setting,	132.5 minutes
c. Final setting,	198 minutes
Hydration temperature 7 days,	65 cal/gr
Normal consistency	25.15 %
Specific gravity	3.03

2.2. Fine Aggregate

Table 2 shows the physical properties of fine aggregate. The fine aggregate in this research is silica sand taken from a local sand mine from a river in Pinrang Regency, South Sulawesi Province. This test was carried out based on the Indonesian National Standard regarding concrete requirements for structural buildings. It can be seen the physical properties of fine aggregates used in this study met the specifications of the Indonesian National Standard (SNI) for concrete materials required.

Table 2. Physical properties of fine aggregate

No.	Property	Value
1.	Spesific gravity	
	-Bulk density	2.58
	-Saturated surface density	2.61
	-Apparent density	2.65
2.	Water absorption	0.91 %
3.	Modulus of fineness	2.95
4.	Volume weight	
	-Loose	1.40 kg/lt
	-Dense	1.48 kg/lt
5.	Water content	3.59 %
6.	Organic content	No. 1

2.3. Mixtures Design of Foam Concrete

The foam concrete mixture design can be seen in Table 3.

Table 3. Mix design foam concrete (m^3)

No	Foam-mortar ratio (by volume)	Mortar			
		Portland Composite Cement (kg)	Water (kg)	Sand (kg)	Naphthalene based superplasticizer (kg)
1	32.53% : 67.47%	662.5	232	1325	16.6
2	55.41% : 44.59%	662.5	232	1325	16.6

In this study, 2 different mix designs were made, where mix designs 1 and 2 had a ratio of foam to mortar by volume of 32.53% : 67.47%, and 55.41% : 44.59%, respevtively. Meanwhile, the mortar composition was kept constant for all mix designs.

2.4. Production of Foam Concrete Specimens and Testing Slump Flow

Foam was prepared in a container. Foam agent was mixed with water in a ratio of 1:3.3 and stirred until stable foam was obtained. Meanwhile, Portland composite cement, fine aggregate, water and superplasticizer were mixed in a mixer to form mortar. The prepared foam was poured into mixer and stirred with mortar to form foam concrete slurry.

Foam concrete slurry was poured into the cylindrical mold with diameter of 10 cm and height of 20 cm without any compaction activity, and then stored in the room with temperature of 27.5 ± 5°C and humidity of 60 RH. After 24 hours, the hardened foam concrete removed from the mold and stored until the age of 3 days and 7 day.

2.5. Indirect Tensile Strength Test

Indirect tensile stregth test ITS testing was carried out on the 3 and 7 days specimens. Specimen was laid horizontally and subjected to a compressive load along the sides to produce tensile stress. The load speed is 5 mm/sec. A load cell was used to measure the given load. In the middle of the two sides, LVDTs were installed to measure the displacements that occurred. Load and displacement measurements were recorded automatically with a computerized data logger set. Furthermore, through the relationship of tensile stress and strain, tensile elastic modulus (Es) was calculated by the equation 1 [13]:

$$E = (\sigma/2)/\varepsilon \quad (1)$$

Where σ is the peak tensile stress; σ/2 is the stress in stress-strain curve which is half of the peak tensile strain; ε is the strain related to σ/2 in the stress-strain curve.

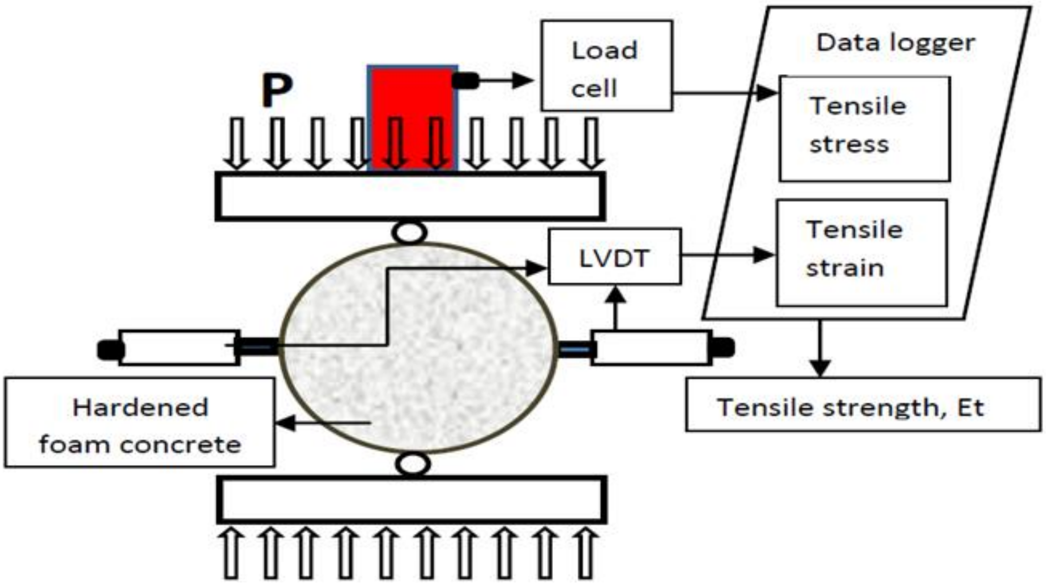

Figure 1. Indirect tensile strength test set up

3. Results and Discussion

Visual observation of the shape and appearance of the test object was carried out before measuring the volume weight of the specimens. All specimens had good shape and appearance without macrovoids, honey combs and no accumulation of fine aggregate at the bottom part. These results indicated that the composition of Portland composite cement superplasticizer mortar combined with foam had a good compatibility and can thus formed stable slurry foam concrete with good self-compaction ability and resistance to segregation during flowing and spreading into the mold.

Table 4 shows volume weight, indirect tensile strength and tensile elastic modulus of the specimens made based on a mix design with foam to mortar ratios of 32.53%: 67.47%, and 55.41%: 44.59%. Each value shown is the average value of the three specimens. At the mix design with the ratio of foam to mortar of 32.53%: 67.47% by volume, the volume weight, indirect tensile strength and tensile elastic modulus were 1508.3 kg/m^3, 0.83 MPa and 207.5 MPa, respectively at 3 days and 1476.9 kg/m^3. 0.89 MPa and 254.3 MPa, respectively at 7 days.

At the mix design with the ratio of foam to mortar of 55.41%: 44.59% by volume, the volume weight, indirect tensile strength and tensile elastic modulus were 1317.2 kg/m^3, 0.37 MPa and 137 MPa, respectively at 3 days and 1283.7 kg/m^3, 0.46 MPa and 200 MPa, respectively at 7 days. Knowledge of volume weight correlated with tensile strength and tensile elasticity at early agewill form the basis for structural applications and the wider usage of Portland composite cement based foam concrete.

Table 4. Volume Weight, Indirect Tensile Strength and Tensile Elastic Modulus

Mix Design	Foam to Mortar ratio	Volume Weight (kg/m^3)		Tensile Strength (MPa)		Tensile Elastic Modulus (MPa)	
		3 days	7 days	3 days	7 days	3 days	7 days
1	32.53%: 67.47%,	1508.3	1476.9	0.83	0.89	207.5	254.3
2	55.41%: 44.59%	1317.2	1283.7	0.37	0.46	137.0	200.0

4. Conclusion

This research produced foam concrete with two ratios of foam to mortar of 32.53%: 67.47%, and 55.41%: 44.59% by volume, respectively, while the composition of Portland composite cement, water, superplasticizer and fine aggregate was kept constant for all mixed designs. Based on the experimental results it can be concluded:

1. The composition of Portland composite cement-superplasticizer mortar in combination with foam established a good compatibility which determined stable foam concrete slurry and can thus form hardened foam concrete.
2. By using foam to mortar ratio of 32.53%: 67.47%, the volume weight, Indirect tensile strength and tensile elastic modulus were 1508.3 kg/m^3, 0.83 MPa and 207.5 MPa at 3 days, respectively and 1476.9 kg/m^3. 0.89 MPa and 254.3 MPa at 7 days, respectively.
3. Foam to mortar ratio of 55.41%: 44.59% by volume, resulted in volume weight, Indirect tensile strength and tensile elastic modulus of 1317.2 kg/m^3, 0.37 MPa and 137 MPa, respectively at 3 days and 1283.7 kg/m^3, 0.46 MPa and 200 MPa, respectively at 7 days

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