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Ultrasonic pulse velocity (UPV) and initial rate of waterabsorption (IRA) of foam concrete containing blendedcement

Y. SUNARNO[1,a*], M.W. TJARONGE[2,b], R. IRMAWATY[2,c], A.B. MUHIDDIN[2,d], M.A. CARONGE[2,e] and M. TUMPU[3,f]

[1]Civil Engineering Department, Faculty of Engineering, University of Christian Indonesia Toraja, Indonesia

[2]Civil Engineering Department, Faculty of Engineering, Hasanuddin University, Makassar, Indonesia

[3]Disaster Management Study Program, The Graduate School, Hasanuddin University, Makassar, Indonesia

[a*]yohanssunarno@gmail.com, [b]tjaronge@yahoo.co.jp, [c]rita_irmaway@yahoo.co.id, [d]bakrim@unhas.ac.id, [e]caronge_eng@yahoo.co.id, [f]tumpumiswa@gmail.com

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Abstract. The adverse environmental effects caused by cement production activities could be minimized by reducing the use of cement in the concrete mix, replacement with eco-friendly materials, and making low-unit weight cement-derived products. During the cement production activities, fly ash can also be used by mixing it in form of Portland Composite Cement (PCC)/blended cement products or directly in the concrete mixing process. Furthermore, in low-unit weight concrete, foam concrete is usually obtained using an agent that forms random air bubblesin the cement paste and is applied in construction according to its structural function. Therefore, this research aims to study and analyze the correlation between unit weight and non-destructive tests (NDTs) valueon foam concrete with variations in the use of cement, namely OPC, PCC-1, PCC-2, and OPC+FA.The quality of the foam concrete was evaluated by non-destructive tests, there are Ultrasonic PulseVelocity (UPV) and Initial Rate of Water Absorption (IRA). The results show that UPV value of all specimens is directly proportional to its unit weight and varied inversely to the IRA value.

Introduction

Portland cement, which is the most important ingredient in concrete, contributes significantly to global warming. This is due to the cement production process contributing nearly 7% of the total carbon dioxide gas into the earth's atmosphere each year which causes greenhouse emissions [1-3]. Therefore, there is a need to minimize the adverse environmental effects by reducing the use of cement in concrete mixtures, replacement with eco-friendlymaterials, and making low-unit weight cement derivative products. Currently, fly ash which is waste from burning coal at the power plant has been widely used as one of the cement substitute materials. This material is usually added to the cement manufacturing process at the factory to form Portland Composite Cement (PCC)/blended cement products or directly to the fresh concrete mixing process. The manufacture of lightweight concrete is to make cement-derived products with the use of less material, as indicated by a lighter unit weight, which ranges from 400 to1850 kg/m^3. One of the developments of these products is foam concrete which uses a foaming agent to form random air in the cement paste. It has the ability as self-compacting concrete, has very low cement content, and reduces the use of aggregates [4,5]. Blended cement produced by a local cement producer has been experimentally tested in the form of foam concrete composite beams [8], and reinforced concrete-filled prefabricated foam concrete walls [7,8].

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Generally, the two methods of testing concrete to ensure the quality of the concrete made as planned include the compressive strength which is destructive and the non-destructive test. A destructive test uses the Universal Testing Machine (UTM) and is carried out in the laboratory by testing several samples to obtain the compressive strength value. The samples can also be tested directly in the field using a tool that measures the compressive strength of hard concrete quickly, practically, and without damage. Meanwhile, a non-destructive method is carried out in the workplace (in situ) to obtain the approximate concrete strength data. The commonly used methods are hammer test, Ultrasonic Pulse Velocity (UPV), and Initial Rate of Water Absorption (IRA).The UPV is a reliable Non-Destructive Testing (NDT) method for monitoring and evaluating concrete quality and detecting damage to its structural components [9]. Several researchers have studied and published the characteristics of concrete using the UPV method [10][11]. In the test procedure according to ASTM C 597-2016 [12], the main principle is to quantify the travel time of the ultrasonic pulse to pass through the tested concrete structure. The ultrasonic waves are channeled from the transmitter transducer on the surface of the concrete to propagate through the material to the receiver transducer. To measure the time taken by a waveform the PUNDIT Read-Out unit (Portable Non-Destructive Indicator Unit Tester) is used in microseconds (msec). Moreover, UPV can also detect several conditions of concrete such as the integrity and uniformity of the concrete, cracks, and depth, honeycombing or voids, the unit weight, and its equivalent in compressive strength. Duringtesting, lower speeds of concrete are indicated by cracking, while better quality in terms of unit weightand homogeneity increases the speed.

The Initial Rate of Water Absorption (IRA) is the total mass of water absorbed for 60 seconds on a 30-square-inch concrete/brick surface area [13]. It is used to determine the level of water absorption from the concrete surface. The test is carried out by calculating the mass increase of the concrete sample due to water absorption at a certain time when one side of the specimen surface is submerged in water. As the hydration occurs and the mortar dries, a chemicalbond forms between the mortar and brick. The brick also needs to absorb enough water and cementfrom the mortar to form the chemical bond within its pores and allow hydration in the joint. The IRA is an important trait that affects the bond and value that can be accepted based on the standards required. If the brick is too dry, it will increase the volume of water absorbed from the mortar, thereby weakening the bond [14].

Therefore, this research aims to study and analyze the correlation between unit weight value and non-destructive test results value (UPV and IRA) of foam concrete with variations in the use of cement, namelyOrdinary Portland Cement (OPC), Portland Composite Cement brand 1 (PCC-1), Portland Composite Cement brand 2 (PCC-2), and Ordinary Portland Cement added fly ash (OPC+FA).

Materials and MethodologyMaterials

This study used OPC and PCC-type cement taken from different brands in South Sulawesi, Indonesia. The types of cement used are OPC, PCC-1, and PCC-2, respectively. Meanwhile, refer to [15] the fly ash used was class F from power plant waste in Jeneponto Regency, South Sulawesi, Indonesia. The data on the physical characteristics and chemical characteristics of all cementitious (OPC, PCC, and fly ash) are shown in Tables 1 and 2. The fine aggregate in this study used siliceous sand sourced from the Pinrang River in Pinrang District, South Sulawesi, Indonesia. The results of their physical characteristics test are shown in Table 3. All materials used in this research met the standard specifications requirement referred to American Standard Testing Method (ASTM).

Mix Design

The mix design of the foam concrete mixture was made with 4 types of variations using Ordinary Portland Cement (OPC), Portland Composite Cement brand 1 (PCC-1), Portland Composite

Cement brand 2 (PCC-2), and Ordinary Portland Cement added fly ash (OPC+30% FA), respectively. The specimen used was a cube-shaped concrete 150 mm x 150 mm x 150 mm. All specimens were treated by air curing in the laboratory with a minimum temperature of 25°C and a maximum of 32°C with a humidity of 60 RH – 74 RH and kept in constant condition until testing.

Unit Weight Tested

The unit weight test is based on [13], which describes the unit weight of structural lightweight concrete standards. The specimens were taken from the curing treatment after 6 days. Specimens were taken from the soaking tub after curing for 6 days. The specimen used is weighed in water and given the initial "C" which is the weight of the specimen in water in a fully submerged condition. Then removed from the water and left for 1 minute by placing the cylinder on a sieve measuring 9.5 mm or more. The water is dried using a damp cloth, its weight is measured, and it is given the initial "B", which is the weight of the specimen in a saturated surface dry state. Then completely dried on the surface in a chamber with humidity at 50% ± 5% and 21°C - 25°C until the weight loss of the specimen is not more than 0.5% at 28 days of age. The dry weight of the specimen is determined and registered in kg with the initial "A". While the weight of the balanced state is calculated according to Equation (1):

$$E_m = (A)/(B\text{-}C)\ (kg/m^3) \quad (1)$$

A is the weight of the specimen at drained condition (kg)

B is the weight of the specimen at saturated surface dry (SSD) condition (kg)

C is the weight of the specimen in water until it is fully submerged condition (kg).

***Table 1**. Physical characteristics of cementitious*

Properties	Result			
	OPC	**PCC-1**	**PCC-2**	**Fly Ash**
Fineness/Blaine meter, m^2/kg	345	448	381	-
Water Content, % volume	-	-	-	-
Autoclave expansion, %	0.10	0.06	-	-
Compressive strength				
3 days, kg/cm^2	190	155	184	-
7 days, kg/cm^2	267	228	260	-
28 days, kg/cm^2	359	285	408	-
Time of setting (Vicat test)				
Initial Set, minute	125	135	132.5	-
Final Set, minute	263	260	195	-
False set, final penetration, %	83.58	86.50	-	-
Air Content, % volume	4.53	4.97	-	-
Specific Gravity	3.10	2.94	3.11	2.05

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***Table 2**. Chemical characteristics of cementitious*

Properties	(%)			
	OPC	**PCC-1**	**PCC-2**	**Fly Ash**
MgO	2.58	1.79	0.99	-
SO_3	2.10	1.72	1.80	-
SiO_2	-	19.66	18.39	44.56
Al_2O_3	-	5.89	5.15	-
Al_2SO_3	-	-	-	14.55
Fe_2O_3	-	4.29	3.12	11.66
SiO_2+Al_2SO_3+Fe_2O_3	-	-	-	69.94
CaO	-	-	63.29	12.69
Loss on ignition	3.38	-	4.60	0.29
Insoluble residue	0.78			
Alkalies	0.30			

***Table 3**. Physical characteristics of sand*

No.	Properties	Result
1.	Unit weight - Dry Unit weight - SSD	 2.60 2.62
2.	Clay Content (%)	0.96
3.	Water absorption (%)	0.88
4.	Fineness Modulus	1.30
5.	Unit weight (kg/lt) - Loose - Congested	 1.29 1.46
6.	Water Content (%)	3.80
7.	Organic Impurities	No. 1

Ultrasonic Pulse Velocity (UPV) Tested

The UPV test used was the direct method, where two transducers were placed on two parallel surfaces as shown in Figures 1 and 2. This method was based on ASTM C 597 [12] using an Electrical Pulse Generator, Transducer, and Amplifier Electronic Timing Device. According to the standard, the test procedures are (a) calibrating the instrument using a calibration cylinder, the ultrasonic pulse speed is set using a calibration cylinder of 57.8 microseconds, (b) smearing both surfaces of the concrete specimen with vaseline or similar material to level the transducer surfaces, and (c) recording the reading of the travel time figures, calculating the speed (v) using the $v=s/t$ relationship, where s is the spacing between the two transducers and t is the time required..

Initial Rate of Water Absorption (IRA) Tested

IRA testing procedures were based on ASTM C67 [17]. In this method, the specimens were dried in an oven at a temperature of 110 - 115°C for 24 hours, removed, and cooled to room temperature. Subsequently, they were weighed when dry (Wd) and their dimensions were measured (L and B) to obtain the surface area of the bricks. The specimens were placed in a partially submerged position in the water until the entire bottom surfaces were in contact with the water and maintained until the end of the test, as shown in Figure 3. When the surface of the specimen is irregular, water for immersion needs to be added. After soaking for 1 minute ± 0.1 seconds, the specimens were taken from the soaking tub and weighed (Ww).

$$X = 30\ W / BL \quad (2)$$

X = gain in weight corrected to the basis of 30 in.^{2} areasW= gain weight of specimen (g)

B = width of specimen (cm)L = length of specimen (cm)

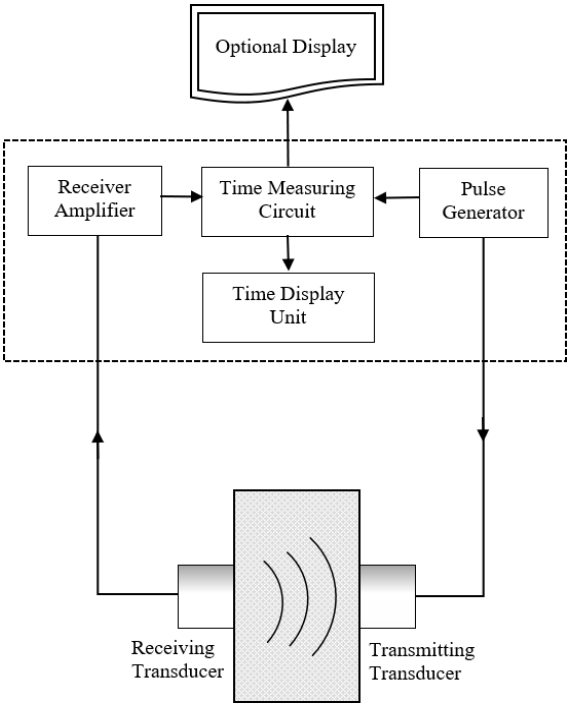

***Figure 1**. Schematic diagram of UPV test circuit*

***Figure 2**. The direct method of UPV test*

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***Figure 3**. Initial Rate of Water Absorption (IRA) test*

Results and DiscussionMixed Design

The foam concrete mix design for the test specimens used in this study can be seen in Table 4. All variations of the mix design use fine aggregate, water, and additives of the same type and volume. Unless cementitious uses OPC, PCC-1, PCC-2, and OPC+FA. The mix design is made in units of 1 m^3.

***Table 4**. Mixed design of foam concrete per m^3*

Material	Type			
	OPC	**PCC-1**	**PCC-2**	**OPC+FA**
Cement, kg	663.4	663.8	663.7	464.8
Sand, kg	1334.7	1325.4	1325.4	1332.5
Fly Ash, kg	-	-	-	199.2
Water, kg	233	232	232	175.5
Admixture, kg	16.7	16.6	16.6	12.5
Total, kg	2247.8	2237.8	2237.7	2237.8
LWC unit weight, gr/ltr	1325	1325	1325	1325
Mortar portion, %	43.9	43.9	43.9	42.9
Foam portion, %	56.1	56.1	56.1	57.1
Foam agent/water ratio				3 : 10

Unit Weight

Figure 4 shows that the average unit weight of hard concrete for each specimen using OPC is 1300 kg/m^3. Furthermore, 1295 kg/m^3 was obtained with PCC-1, while PCC-2 is 1287 kg/m^3. The average unit weight of hard concrete test objects using fly ash (OPC+FA) is 1279 kg/m^3. Referring to ACI 213R3 [11], the unit weight of all test objects can be categorized as light structural concrete, where the unit weight in range between 800 kg/m^3 - 1400 kg/m^3.

Ultrasonic Pulse Velocity (UPV)

From Figure 5, we can show that the results of the UPV test of hard concrete for each specimen using OPC is 2.781 km/s. The PCC-1 is 2.625 km/s, while PCC-2 is 2.599 km/s. Furthermore, 2.552 km/s was obtained using fly ash (OPC+FA). According to the International ACI 228.2R-13 [18], all specimens are included in the category of concrete with doubtfully quality, which is below 3.000 km/s.

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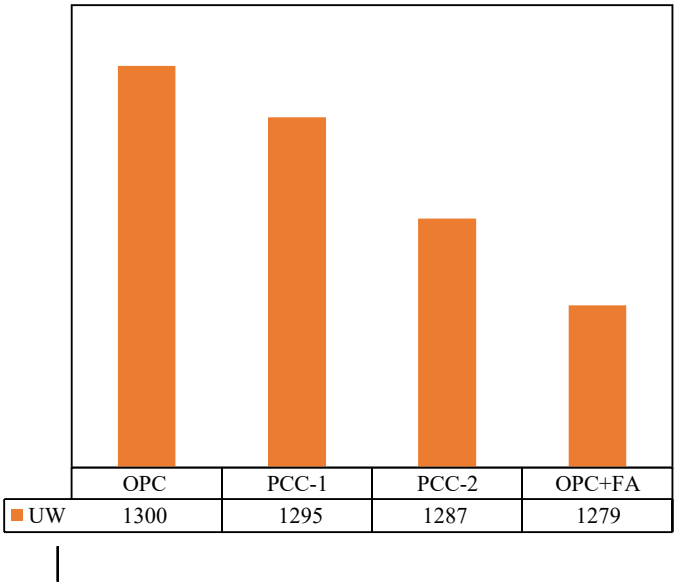

***Figure 4**. Unit weight result*

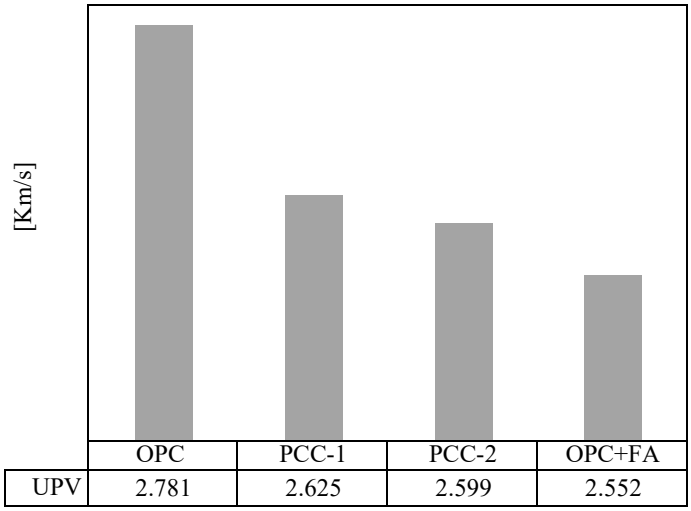

***Figure 5**. UPV tested result*

Initial Rate of Water Absorption (IRA)

Based on Figure 6, the values of the Initial Rate of Water Absorption (IRA) test on each specimen, hard concrete using OPC is 14.947 gr/cm^2. The use of PCC-1 obtained 15.178 gr/cm^2, while PCC-2 is 17.093 gr/cm^2. Moreover, fly ash (OPC+FA) is 18.627 gr/cm^2. Based on ASTM C90 [19], as lightweight concrete, the IRA values for all specimens meet the requirements, namely below 20 gr/cm^2.

Relationship Between Unit Weight, UPV, and IRA

Figure 7 indicates that a decrease in the unit weight of the specimen occurs when the UPV test value of the specimen also decreases.This showed that the smaller the value, the greater the concrete unit weight, thereby, reducing the Ultrasonic Pulse Speed (UPV value). However, with a decrease in the specimen's unit weight, the IRAvalue will be greater. This is because the unit weight increases the speed of water absorption by the concrete surface.

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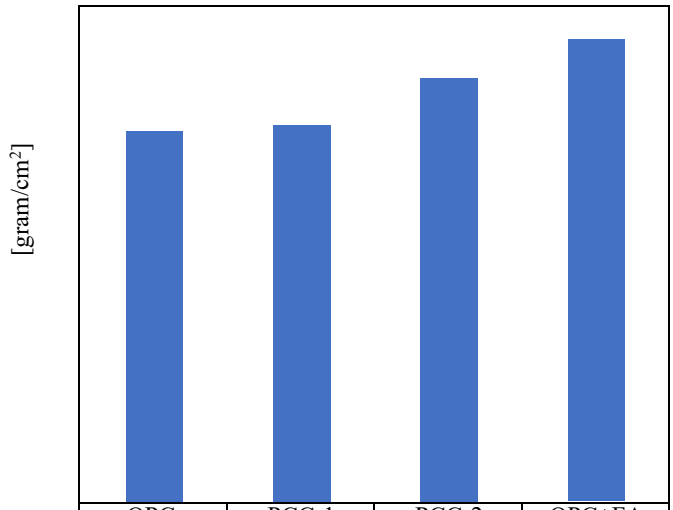
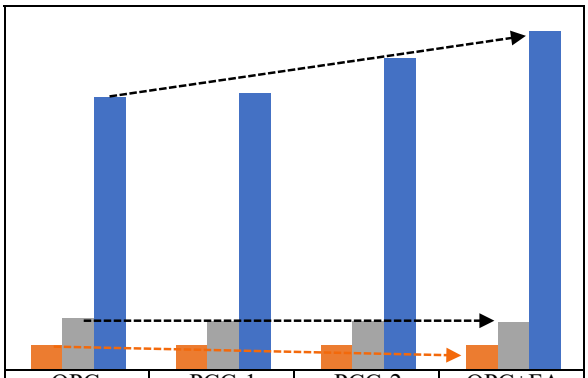


	OPC	PCC-1	PCC-2	OPC+FA
IRA	14.947	15.178	17.093	18.627

***Figure 6**. IRA tested result*



	OPC	PCC-1	PCC-2	OPC+FA
UW	1300	1295	1287	1279
UPV	2.781	2.625	2.599	2.552
IRA	14.947	15.178	17.093	18.627

***Figure 7**. Relationship between unit weight, UPV, and IRA*

Conclusion

Referring to the results, the following conclusions are obtained:

1. OPC specimen has the highest unit weight of 1300 kg/m^3, while the OPC+FA has the lowest, with a value of 1279 kg/m^3. Based on ACI 213R3, all test specimens were categorized as lightweight structural concrete, which unit weight values from 800 kg/m^3 to 1400 kg/m^3.
2. The OPC specimen has the highest UPV value of 2.781 km/s, while the OPC+FA has the lowest,which is 2.552 km/s. Therefore, according to ACI 228.2R-13, all specimens are in the category of concrete with doubtfully quality, which is below 3.000 km/s.
3. The OPC specimen has the lowest IRA value of 14.947 gr/cm^2, while the OPC+FA test objecthas the highest, which is 18.627 gr/cm^2. Referring to ASTM C90, as lightweight

concrete, the IRA values for all specimens meet the requirements, namely below 20 gr/cm$^{2.}$

4. The UPV value of the specimen is directly proportional to its unit weight and varied inversely to the IRA value.

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