Ultrasonic Pulse Velocity and Initial Rate of Water Absorption Of Foam Concrete Containing Blended Cement

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Abstract— **This The adverse environmental effects caused by cement production activities are minimized by reducing the use of cement in the concrete mix, replacement with eco-friendly materials, and making low-material 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-material cement derivative products, foam concrete is usually obtained using an agent that forms random air bubbles in the cement paste and is applied in construction according to its structural function. Therefore, this study aims to analyze the correlation between density and non-destructive tests (UPV and IRA) on 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 testing the compressive strength, which is fast, practical, and non-destructive. The methods that are commonly used include the Hammer test, Ultrasonic Pulse Velocity (UPV), and Initial Rate of Water Absorption (IRA). The results showed that the correlation between UPV and IRA is inversely proportional because an increase in the UPV value in the specimen reduced the IRA value.**

Keywords— **blended cement, fly ash, NDTs, UPV, IRA.**

I. Introduction

Portland cement is the main material in construction and a major contributor to greenhouse gas emissions that cause global warming. It contributes 6-7% of the total CO_2 gas to the earth's atmosphere annually [1]. Therefore, there is a need to minimize the adverse environmental effects by reducing the use of cement in concrete mixtures, replacement with eco-friendly materials, and making low-material cement derivative products. Currently, fly ash which is a 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 of 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 density, which ranges from 400 to 1,850 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 high flowability, low cement content, and efficient use of aggregates [2], [3]. Blended cement produced by a local cement producer has been experimentally tested in the form of foam concrete composite beams [4], and reinforced concrete filled prefabricated foam concrete walls [5], [6].

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, 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) [7], and Initial Rate of Water Absorption (IRA).

The UPV is an effective Non-Destructive Testing (NDT) method to control the quality of the concrete material and detect damage to its structural components. In the test procedure according to ASTM C 597-2016, the main principle is to measure 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. The wave travel time is measured by the Read-Out unit PUNDIT (Portable Unit Non-Destructive Indicator Tester) 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 density, and its equivalent in the compressive strength. During testing, lower speeds of concrete are indicated by cracking, while better quality in terms of density and homogeneity increases the speed.

Initial Rate of Water Absorption (IRA) is the mass amount of water absorbed for one minute on a 30 square inch concrete/brick surface area [8]. It is used to determine the level of water absorption from the concrete surface. The test is carried out by calculating the increase in the mass of the concrete sample from water absorption as a function of the time when one side of the specimen's surface is exposed to water. As the hydration occurs and the mortar dries, a chemical bond forms between the mortar and brick. The brick also needs to absorb enough water and cement from the mortar to form the chemical bond within its pores and allow hydration in the joint. The IRA is an important trait that affects bonding and its acceptable values range from 10 to 30 grams. When the brick is too dry, it will absorb excess water from the mortar used and weaken the bond.

Therefore, this study aims to analyze the correlation between density and non-destructive test results (UPV and IRA) of foam concrete with variations in the use of cement, namely OPC, PCC brand 1 (PCC-1), PCC brand 2 (PCC-2), and OPC+FA.

II. Material and Methodology

A. Material

The 2 types of cement used were OPC from 1 certain brand and PCC from 2 different brands, namely PCC-1 and PCC-2, which were obtained at local cement producers in Sulawesi, Indonesia. Meanwhile, refer to [9] the fly ash used was class F from PLTU waste in Jeneponto Regency, Sulawesi. The data on the physical and chemical characteristics of cement and fly ash are shown in Tables 1 and 2.

TABLE I
PHYSICAL CHARACTERISTICS OF CEMENT AND FLY ASH

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	-	-
Heat of hydration 7-day, Cal/gr	-	-	66	-
Air Content, % volume	4.53	4.97	-	-
Specific Gravity	3.10	2.94	3.11	2.05

TABLE 2
CHEMICAL CHARACTERISTICS OF CEMENT AND FLY ASH

Properties	Content (%)			
	OPC	PCC-1	PCC-2	Fly Ash
MgO	2,58	1,85	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
$SiO_2+Al_2SO_3+Fe_2O_3$	-	-	-	70,94
CaO	-	-	61,79	12,74
Loss on ignition	3,38	-	4,60	0,29
Insoluble residue	0,78			
Alkalies	0,30			

The fine aggregate used was silica sand from Pinrang Regency, Sulawesi, Indonesia, and the results of their physical characteristics test are shown in Table 3

TABLE 3
PHYSICAL CHARACTERISTICS OF FINE AGGREGATE

No.	Properties	Result
1.	Density - Dry Density - SSD	 2,60 2,62
2.	Clay Content (%)	0,96
3.	Water absorption (%)	0,88
4.	Fine Modulus	1,30
5.	Unit weight (kg/lt) -Loose -Solid	 1,29 1,46
6.	Water Content (%)	3,80
7.	Organic Impurities	No. 1

B. Mix Design

The design of the foam concrete mixture was made with 4 types of variations using OPC, PCC-1, PCC-2, and OPC with 30% fly ash, respectively. The specimen used was a cube-shaped concrete 15 cm x 15 cm x 15 cm. All specimens were stored and treated with curing in a room in the laboratory at a temperature range from 25°C to 32°C with a humidity of 60 RH – 74 RH until the time of testing.

C. Density Test

The density test is based on [10], which describes the density of structural lightweight concrete. The specimens were removed from the treatment conditions after 6 days and immersed in water at a temperature of 23 ± 2ºC for 24 hours. The cylinder used was weighed in water (fully submerged) and recorded with the code "C", which is the weight of the cylinder in water until it is fully submerged. Subsequently, it was removed from the water and left for 1 minute by placing the cylinder on a 9.5 mm or coarser sieve. The water was dried with a damp cloth, weighed, and recorded with the code "B", which is the weight of the cylinder in the dry state of the saturated surface. They were dried completely on the surface in a humidity-controlled room at 50% ± 5% and at a temperature of 23º C ± 2º C until the weight loss of the specimens was not more than 0.5% at the age of 28 days. The dry weight of the cylinder was determined and recorded in kg with the code "A". Meanwhile, the weight of the balanced state is calculated according to equation (1)

$$E_m = (Ax997)/(B\text{-}C)\ (kg/m^3) \qquad (1)$$

A is the weight of the cylinder that has been drained (kg)
B is the weight of the cylinder at dry surface saturation (kg)
C is the weight of the cylinder in water until it is fully submerged (kg).

D. Ultrasonic Pulse Velocity (UPV) Test

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 [11] using an Electrical Pulse Generator, Transducer, and Amplifier Electronic Timing Device. According to [11], 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 distance between the transducers and t is the travel time.

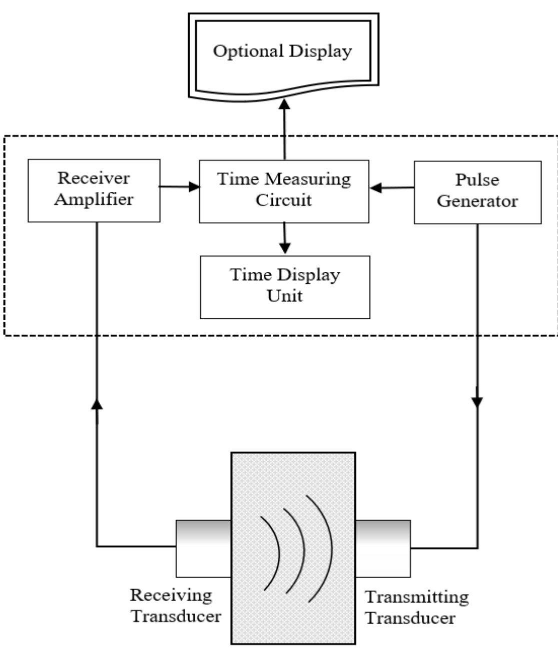

Fig. 1 Schematic diagram of UPV test circuit

Fig. 2 Direct mehode of UPV test

E. Initial Rate of Water Absorption (IRA) Test

The IRA testing procedures were based on ASTM C67 [8]. 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 removed from the water and weighed (Ww).

$$X = 30\ W / LB \qquad (2)$$

X = gain in weight corrected to the basis of 30 in.^{2} (193.55 cm^2) flatwise area
W = actual gain in weight of specimen (g)
L = length of specimen (cm)
B = width of specimen (cm)

Fig. 3 Initial Rate of Water Absorption (IRA) test

III. Result and Discusion

A. Mix Design

The mix design of the concrete for the test specimens used is presented in Table 4. The mix design of this mixture is in units of 1 m^3.

TABLE 4
Foam Concrete Mid Design (per m^3)

Material	Mixed Type			
	OPC	**PCC-1**	**PCC-2**	**OPC+FA**
Cement (kg)	663.40	663.8	663.70	502.37
Sand (kg)	1334.7	1325.4	1325.43	1332.52
Fly Ash (kg)	-	-	-	214.88
Water (kg)	233	232	232	175.48
Admixture1 (kg)	16.69	16.57	16.57	12.53
Total (kg)	2247.79	2237.77	2237.70	2237.78
LWC density (gr/ltr)	1325	1325	1325	1325
Mortar portion (%)	44.4	44.4	44.4	42.8
Foam portion (%)	55.6	55.6	55.6	57.2
Ratio of foam agent/water	3 : 10			

B. Density

The density of hard concrete for each specimen using OPC ranged from 1249 kg/m^3 to 1354 kg/m^3. Furthermore, a range from 1289 kg/m^3 to 1302 kg/m^3 was obtained with PCC-1, while PCC-2 ranged from 1298 kg/m^3 to 1342 kg/m^3. The density of hard concrete test objects using fly ash (OPC+FA) ranged from 1237 kg/m^3 to 1327 kg/m^3. Based on ACI 213R3 [12], the density of all test objects meets the requirements for the lightweight structural concrete category, which is between 800 kg/m^3 to 1400 kg/m^3.

C. Ultrasonic Pulse Velocity (UPV)

The results of the UPV test of hard concrete for each specimen using OPC ranged from 2.732 km/s to 2.795 km/s. The PCC-1 ranged from 2.492 km/s to 2.796 km/s, while PCC-2 ranged from 2.356 km/s to 2.470 km/s. Furthermore, a range of 2.487 km/s to 2.606 km/s was obtained using fly ash (OPC+FA). According to the International Atomic Energy Agency, Vienna, 2002:110 [13], all specimens are included in the category of concrete with poor quality, which is between 2.000 km/s to 3.000 km/s.

D. Initial Rate of Water Absorption (IRA)

Based on the results of the IRA test on each specime, hard concrete using OPC ranged from 10.867 gr/cm^2 to 18.400 gr/cm^2. The use of PCC-1 obtained a ranged from 12.293 gr/cm^2 to 18.173 gr/cm^2, while PCC-2 ranged from 15.600 gr/cm^2 to 19.640 gr/cm^2. Moreover, fly ash (OPC+FA) also ranged from 13.667 gr/cm^2 to 24.447 gr/cm^2.

E. Relationship Between Density, UPV and IRA

Figure 5 shows that the decrease in density is proportional to the reduction in the UPV test value. This showed that the smaller the value, the greater the concrete density, thereby, reducing the Ultrasonic Pulse Speed (UPV value). However, with a decrease in the specimen's density, the IRA value will be greater. This is because the density increases the speed of water absorption by the concrete surface.

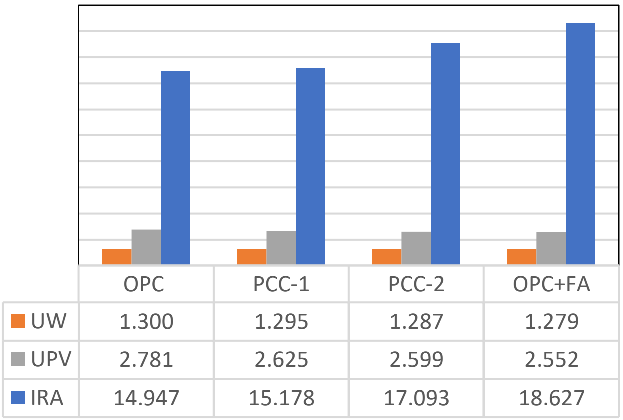

Fig. 4 Relationship between Density, UPV and IRA

Based on the results, the following conclusions are obtained:

1. The OPC specimen has the highest density 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 met the requirements for the lightweight structural concrete density category, which ranged 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 the International Atomic Energy Agency, Vienna, 2002: 110, all specimens are in the category of concrete with poor quality, which is from 2.000 km/s to 3.000 km/s.
3. The OPC test object has the lowest IRA value of 14.947 gr/cm^2, while the OPC+FA test object has the highest, which is 18.627 gr/cm^2.
4. The UPV value of the specimen is directly proportional to its density and varied inversely to the IRA value.

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