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Early Age Thermal Behavior and Strength of Mass Concrete using Portland Composite Cement

Anshar M.W. Tjaronge, Rudy Djamaluddin and A. Arwin Amiruddin
Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Gowa, South Sulawesi Province, Indonesia

Key words: Portland Composite Cement (PCC), mass concrete, thermal heat, compressive strength, indirect tensile strength

Corresponding Author:
Anshar M.W. Tjaronge
Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Gowa, South Sulawesi Province, Indonesia

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Abstract: The blended cement containing pozzolan have developed in America, Japan and many European countries. In recent decades, the blended cement consisting of by products such as fly ash has been developed by national cement factories. One of a blended cement made in Indonesia cement plant is Portland Composite Cement (PCC). At present in Indonesia the majority of construction works use PCC.Many mass concrete structures such as dams are currently being built in Indonesia with use PCC as binder. One important factor is the variation in the high temperature at the early age of the mass concrete after pouring. The strength development at early age of the mass concrete caused by the hydration heat generated from the blended cement such as PCC was a focus in this study. After fresh concrete was poured into a 1.2×1.2×1.2 m mass concrete, the temperature inside was measured to study the thermal heat produced by PCC hydration. In an effort to understand the relationship of thermal heat with the strength of mass concrete at an early age at the age of 3 and 7 days core specimens were taken to be tested for compressive strength and indirect tensile strength. From the results of testing it can be seen that the development of compressive strength and indirect tensile strength from 3-7 days in 1.2×1.2×1.2 m of mass concrete using PCC can be attributed to the hydration and interface binding process on aggregates and cement paste has been going well even though it has experienced a high temperature of 61.5°C.

INTRODUCTION

In Indonesia, many electric power plants use coal as material to generate electricity. Fly ash is a by-product derived from burning coal to produce electricityin the electric power plants. At present, most of the fly ash is dumped into landfills in the form of lakes which cause environmental damage. The deterioration in environmental quality due to the continuous production of fly ash as a by-product of coal combustion is a driving force to see its use as construction material in connection with efforts to reduce the amount of fly ash discharged and reduce the use of land for fly ash disposal.

Some cement producers in Indonesia have adopted blended cement which has been developed in several countries in Europe, America, Japan and others, where fly ash is one of the pozzolan materials that can be mixed with Portlandcement clinker to produce blended cement. In the last few decades, in Indonesia, based on consideration of nature conservation, reduction of waste such as fly ash, reduction of CO_2 emission and other factors related to sustainable infrastructure development, there has been a strong tendency towards developing additional alternatives for the production of eco friendly blended cement such as Portland Composite Cement (PCC). Initially, PCC was made based on the rule of 2004 (SNI 15-7064-2004)[1] which subsequently updated in 2012 with SNI 15-7064-2012[2]. A number of studies using PCC in the concrete production show that PCC as a binder contributes positive results on the concrete properties.

It is a basic knowledge that concrete hydration is an exothermic activity and generates significant heat formation in mass concrete. After casting, concrete turns into a bad conductor that can hold hydration heat for a long period. Depending on the dimension of the mass concrete structure, the hydration activity can extend for several years on massive structures such as dams to reach a steady temperature distribution in balance with the encircling environmental states.

The repetitive action of cooling and drying in concrete has relation with the volumetric changes that creates shrinkage and results in volumetric strain in concrete due to internal restraints of hardened concrete and other external restraint. Cracks can occur if the stress value exceeds the tensile stress capacity of the concrete. A thermal stress analysis on the mass concrete needs totake into account a number of parameters including several time-dependent factors. These factors comprise concrete hydration that generates heat, initial temperature of fresh concrete when poured, schedule and layers of mass concrete pouring, solar radiation level that heats the mass structures, heat dissipation through convection and evaporation of water on the surface, physical properties of hardened concrete with are time-dependent (creep, shrinkage, modulus of elasticity and tensile and compressive strength) and strain of concrete due to thermal and gravity loads[3-5].

In Indonesia, recently many massive concrete structures have been built and some of them are dams. Because PCC is the most widely and easily available in the local market, so much of the construction of dams or other massive concrete structures use PCC as the main binding material. As mentioned before, PCC is one type of blended cement containing pozzolan material in the form of fly ash which was newly developed in 2005, so knowledge of the application of PCC as a binder in mass concrete construction is still very limited. Therefore, it is important to compile a research that investigates the use of PCC in mass concrete and characterizes physical properties when the concrete is fresh or when it has hardened condition.

The research reported in this study was one of a series of studies aimed at developing a relationship between PCC as a binder and the physical characteristics of concrete mass. The research in this paper focused on the use of PCC in the manufacture of mass concrete, where changes in the temperature of the concrete mass with dimension of 1.2×1.2×1.2 m was recorded and the compressive strength and indirect tensile strength of hardened concrete using core concrete specimens taken from 1.2×1.2×1.2 m of mass concrete at the early age of 3 and 7 days was evaluated.

MATERIALS AND METHODS

Portland Cement Composite (PCC): Table 1 shows the physical properties of PCC used in this study. Table 2 shows the chemical compounds of PCC (XRF-X-ray fluorescence test results). Based on physical properties of the PCC shown in Table 1, it can be seen that the PCC used in this study met the Indonesian National Standard (SNI 15-7064-2012) specifications for PCC.

Based on Table 2 it can be seen that the chemical compound of the cement used as a binder is dominated by the CaO and silica (SiO_2) elements, which are 61.79% and 18.39%. Whereas the other elements, MgO, SO_3, Al_2O_3, Fe_2O_3, LOI (Loss of Ignation) are 0.99%, 1.81%, 5.15%, 3.14 and 4.61%, respectively.

Aggregate: Physical properties tests were carried out to determine the suitability of the material used. The material used in this study consisted of natural aggregates, namely fine aggregates in the form of river sand and crushed stones. This test was carried out based on Indonesian National Standard regarding concrete requirements for structural buildings. Data of physical properties of coarse and fine aggregate can be seen in Table 3 and 4, respectively. It can be seen the physical properties of coarse aggregate with size of 10- 20 mm and 20-40 mm and fine aggregates used in this study met the specifications of the Indonesian National Standard (SNI) for concrete materials required.

Mix design: The design of a mixture of mass concrete was concrete with compressive strength design f'c = 22.5 Mpa that applied in a mass concrete with a size of 1.2×1.2×1.2 m. Table 5 shows the mix design of a concrete mixture with f'c = 22.5 Mpa in 1 m^3. The mixture design used was based on trial and

Table 1: Physical properties of PCC cement

Physical properties	SNI 15-7064-2012 standard	Results
Water content (%)	12 max	11.5
Fineness	280 min	382
Expansion (max) (%)	0,80 max	-
Compressive strength		
3 days (kg cm^{-2})	125 min	185
7 days (kg cm^{-2})	200 min	263
28 days (kg cm^{-2})	250 min	410
Setting time (Vicat test)		
Initial setting (minutes)	45 min	132.5
Final setting (minutes)	375 min	198
Fake setting time	50 min	-
7 days hydration temperature (cal/gr)		65
Normal consistency (%)		25.15
Specific gravity		3.03

Table 2: Chemical compounds of cement (XRF test results)

Compounds	Content (%)
MgO	0.99
SO_3	1.81
SiO_2	18.39
Al_2O_3	5.15
Fe_2O_3	3.14
CaO	61.79
LOI	4.61

Table 3: Physical properties of coarse aggregate

Physical properties	Coarse aggregate 10-20 mm	Coarse aggregate
20-40 mm		
Moisture content (%)	1.10	1.10
SSD density	2.52	2.56
Bulk density	2.44	2.47
Specific gravity	2.67	2.70
Water absorption (%)	3.59	3.44
Abrasion	23.09	23.09

Table 4: Physical properties of fine aggregate

Physical properties	Kelarariver	Saddang river
Saturated surface density	2.52	2.52
Bulk density	2.46	2.46
Apparent density	2.69	2.60
Water absorption (%)	1.49	2.00
Modulus of fineness	2.82	2.52

mixexperiments that have been carried out according to the expected concrete quality plan and the specified slump.

Concrete molds and heat measuring device: Figure 1 shows a 1.2×1.2×1.2 m box used to test the temperature that occurred in a mass concrete using PCC. Two thermocouple instruments were installed in the middle and upper parts as shown in Fig. 1. All thermocouple instruments were installed in the center of the mass concrete with a depth of 15 cm and 60 cm from the surface.

Concrete core specimens: In order to determine the effect of the temperature of the mass concrete on the strength development of the concrete, core specimens were taken from the mass concrete of 1.2 m×1.2 m×1.2 m. The depth of the test specimen was 30 cm from above and about 20-40 cm from the edge. After being cored from the mass concrete, the core specimens were stored in a laboratory at temperature of 27±0.5°C and humidity 60 RH.

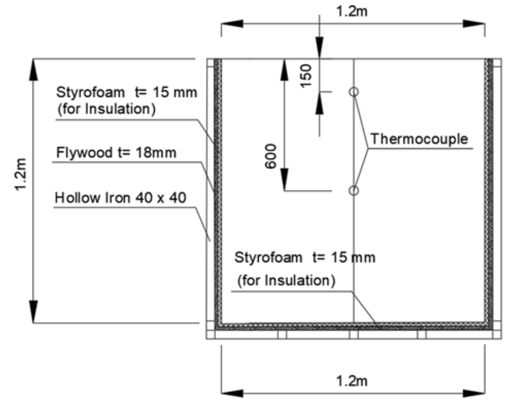

Fig. 1: 1.2 m×1.2 m×1.2 m box

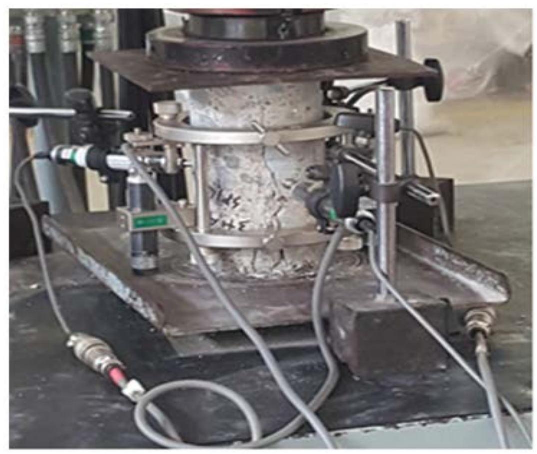

Fig. 2: Equipment for the compressive strength test

Strength testing: Compressive strength test equipment was used to produce compressive stress. Compressive strengthmeasured based on the peak load received divided by the cross-sectional area of the concrete core specimen. The Indirect Tensile Strength (ITS) was conducted by loading a cylindrical concrete core specimen across its vertical diametralplane until failure. Figure 2 shows the equipment for the compressive strength test and Fig. 3 shows the equipment for the indirect tensile strength test. Compressive strength and indirect tensile strength tests were recorded and monitored using a data logger and a set of computer systems. Figure 4 shows a set of data logger and computer for recording applied loads (Table 5 and 6).

Table 5: Mixed f'c = 22,5 box design with 1.2 m×1.2 m×1.2 m size

	Calculation			
Concrete material	Volume (m^3)	Values	Weight (kg)	Values
Water	190/(1000×1000)	0.190		190,00
Cement	431,8/(3000×1000)	0.144		431,82
Air	1,2%	0.012		
Admixture	Retarder	0.001	1,1/(1180×1000)	1,08
	Superplasticizer	0.005	6,5/(1190×1000)	6,48
Aggregate	Sand	0.311	0,311×2,545×1000	791,23
	Stone crusher	0.168		
10-20 mm		0.168	0,168×2,529×1000	425,89
	Stone crusher 20-40 mm	1.000	0,168×2,563×1000	431,62
Total				2.278,12

Table 6: Summary of important data from mass concrete measurements measuring 1.2×1.2×1.2 m

		Highest temperature	
Point	Initial temperature after casting (°C)	Time to reach the highest temperature (h)	Highest temperature (°C)
Air	28.0	-	Air
Middle	34.0	46.0	Middle
Upper	38.0	46.0	Upper

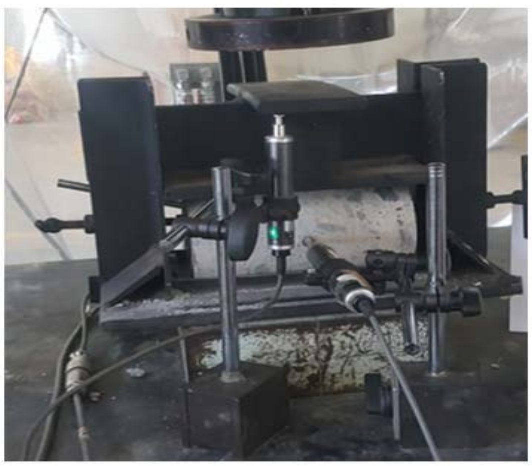

Fig. 3: Equipment for the indirect tensile strength test

Fig. 4: A set of data loggers and computers

RESULTS AND DISCUSSION

Early age thermal: Table 6 shows a summary of important data from the measurement of mass concrete with dimension of 1.2×1.2×1.2 m. In the first measurement after casting it was seen that the temperatures in the middle and above are 34.0°C and 38.0°C, respectively. The highest temperature reached 61.5°C which was still below the maximum permitted temperature of 70°C (ACI 207.1R-05). The difference or temperature gradient between layers was around 3.2°C and the value was less than the maximum allowable temperature difference of 20°C (ACI 207.1R-05).

Strength of concrete core at 3 and 7 days: Table 7 shows the compressive strength of core specimen taken from mass concrete of 1.2×1.2×1.2 m at 3 and 7 days. At 3 days, from 3 test samples, it shows that three 3-days concrete core specimens had almost the same strength and the average compressive strength value was 10.29 MPa. At 7 days, the compressive strength value of concrete core1, 2 and 3 almost same, The compressive strength of concrete at the age of 7 days was 15.18 MPa.

Table 8 shows the indirect tensile strength of concrete core specimen taken from mass concrete of 1.2×1.2×1.2 m at 3 and 7 days. At 3 days from the average of 3 test samples, the indirect tensile strength was 2.08 MPa. The indirect tensile strength of concrete at the age of 7 days was 2.98 MPa.

The compressive strength value at the age of 7 days was 39.12% higher than the compressive strength value at 3 days, whereas the indirect tensile strength value at the age of 7 days was 30.20% highest than the compressive strength value at 3 days. This shows that the hydration process was going well from the time of casting and the interface between aggregate and cement paste which

Table 7: Compressive strength of concrete at early age

No. of samples	Days	Compressive strength (Mpa)
1	3	10.50
2		10.68
3		9.69
Average		10.29
1	7	15.35
2		14.98
3		15.20
Average		15.18

Table 8: Indirect tensile strength of concrete at early age

No. of samples	Days	Indirect tensile strength (Mpa)
1	3	2.12
2		2.00
3		2.12
Average		2.08
1	7	2.98
2		2.94
3		3.02
Average		2.98

increased with age and improved in strength within the 1.2×1.2×1, 2 m mass concrete dimension that used PCC.

CONCLUSION

From the results of testing it can be seen that the development of compressive strength and indirect tensile strength from 3-7 days in 1.2×1.2×1.2 m of mass concrete using PCC can be attributed to the hydration and interface binding process on aggregates and cement paste has been going well even though it has experienced a high temperature of 61.5°C.

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