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Thermal Cracking Mitigation in Mass Concrete on Preplacing Aggregate Concrete Method with Pozzolanic Materials

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Abstract. Fly ash is known as a waste from burning coal which has answered the issue of global warming to be an alternative constituent material for concrete. Casting on mass concrete has a major problem like the thermal cracking caused by the hydration process in the cement chemical component. The prevention solution is using fly ash for a mixed design. Moreover, the casting method using the preplacedd aggregate method could be able to control the heat of hydration which lowers the temperature of the concrete by minimalizing the friction between the coarse aggregate particles during the mixing operation. This study aims to analyze the behaviour of surface and core temperatures in mass concrete using the preplacedd aggregate concrete method and substituting part of the cement with fly ash. The result from the study showed that the temperature behaviour of preplacedd aggregate concrete for mass concrete decreased and slowed the temperature rise if compared to the conventional methods. Moreover, the partial substitution of class C fly ash in the concrete mixture leads to reduce the temperature of the mass concrete.

1. Introduction

1.1. Research Context

Concrete is a rock-like material obtained by making a mixture that has certain constituent materials that consist of cement, fine and coarse aggregates, and water [1]. Mass concrete is normally concrete with a large volume of construction and associated with in situ concreting. Mass concrete is usually considered if its dimensions are more than 60 cm, often used in dam construction, bridge construction as pillars and high-rise buildings construction as raft foundations which are commonly referred to as raft foundations. [2]-[3].

The main consideration in large casting is heat control [4]-[8]. After pouring the concrete into the mould, it releases the heat of hydration that arises as a reaction of water and cement. Cement hydration is an exothermic process that leads to an increase in the temperature of the concrete core. The increase in temperature at the core can cause a temperature difference to the base and surface of the mass concrete as well as the ambient (room temperature) so it can cause changes in volume. If there is a large volume it will cause a temperature deviation, then thermal cracking occurs in the mass concrete. The heat on the surface of the mass concrete is more easily released to the surrounding air, while in the concrete core the temperature remains high. This causes a temperature difference in the mass concrete and then causes internal stresses in the concrete which then cause thermal cracking. Cement is a binder in concrete mixtures because it has adhesion and cohesion properties that can bind other materials into a single unit.

The cement reaction is an exothermic reaction, which is a reaction that releases heat. The heat of hydration depends on the chemical composition of the cement and the amount of heat of hydration produced by the constituent materials. The time required for cement to change from liquid to hard is called setting time. The setting time is accompanied by changes in the temperature of the cement paste. The initial setting is characterized by a rapid rise in temperature and the final setting corresponds to the peak temperature. Additives are used to modify concrete properties and characteristics, which are usually given in relatively small quantities. One of the added materials used is fly ash, which is an alternative waste to replace cement, which is obtained from coal combustion. Furthermore, SNI ASTM C618 [9] defines the meaning of fly ash as waste from burning coal in a steam power plant furnace that is smooth, round and pozzolanic. Fly ash as a pozzolanic material is a material containing silica or silica and alumina compounds; Independently no binding ability (non-cementitious); In a very fine form it can react with calcium hydroxide with sufficient moisture and at room temperature to form a material that has cementitious properties.

Fly ash mainly consists of silicate glass compounds containing silica (Si), alumina (Al), Ferrum (Fe), and calcium (Ca). Fly ash classification is generally done by taking into account the levels of chemical compounds (SiO_2 + Al_2O_3 + Fe_2O_3), levels of CaO (high calcium and low calcium), and carbon content (high carbon and low carbon). The carbon content that affects the Loss on Ignition is set not to be more than 6 per cent (class F and C) or 10 per cent (class N). Fly ash which can be used as a partial replacement of cement in concrete is regulated in the ACI Manual of Concrete Practice 1993 Part 1226.3R and ASTM C 618 (Standard Specification for Coal and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement concrete). Class C fly ash is also called high-calcium fly ash because of its high CaO content. Type C fly ash has cementitious properties as well as pozzolanic properties. Because Fly ash type C contains a fairly high level of CaO and has cementitious properties, when exposed to water or moisture, it will hydrate and harden in about 45 minutes. In the use of added materials, the content of fly ash that is loaded must also take into account the content of pozzolan that has been mixed in the cement.

The previous research from Bayer [10] describes that the addition of mineral additives in the manufacture of mass concrete can reduce temperature much more effectively than controlling hydration. Moreover, other previous researchs conclude the similar result [11]-[12].

1.2. Research Aims

Cracks caused by this thermal effect in mass concrete can be overcome with several solutions, one of which is the use of fly ash as a partial replacement of cement. This substitution can reduce heat because the hydration process of cement is reduced due to the reduction of cement material. Fly ash is a popular additive today to be used as a partial replacement for cement in concrete mixtures. Based on this description, the research was conducted to determine the temperature behaviour of the surface and core of mass concrete using the preplaced method and the conventional method as temperature control with a thermocouple device, and partial replacement of cement with fly ash.

2. Method and Material

The research started by collecting materials, namely: cement, fine aggregate, coarse aggregate, fly ash, superplasticizer and water. The materials used in this study were a fine aggregate of Barito sand, PCC cement and Fly ash. Physical characteristics of fine, coarse aggregates and cementitious materials are determined first in table 1 and table 2 also figure 1 and 2.

Table 1. Physical characteristics of fine aggregates and cementitious materials

Characteristic	Material 1		Material 2		Material 3	
	Observed value	Code	Observed value	Code	Observed value	Code
Name	Barito sand	-	PCC Cement	SNI 15-7064-2004	Fly ash	SNI 03-2460-1991
Type	Mild sand	-	-	-	C	-
Grade Zone	III	-	-	-	-	-
Specific gravity	2.65 gr/cm^3	SNI 1970:2016	3.077 gr/cm^3	-	1,9 – 2,55 gr/cm^3	-
Water content	5%	SNI 1970:2016	-	-	105	-

(a) Barito Sand (b) PCC Cement (c) Fly ash

Figure 1. Fine Aggregates and Cementitous Material of Mass Concrete

Table 2. Physical characteristics of coarse aggregates

Characteristic	Data and value	
	Observed value	Code
Name	Katunun	
Water content	0.25%	SNI 1969:2016
Spesific gravity	2.86 gr/cm^3	SNI 1969:2016
Volume weight	1.56 gr/cm^3	
Abrasion value	11.90%	SNI 2417:2018

Figure 2. Coarse Aggregate of Mass Concrete

The fly ash used comes from the waste of the Steam Power Plant of Rimau Electric Ltd in Tamiang Layang City, Central Kalimantan Province; Based on the results from the examination of the Fly ash chemical properties, it is categorized into class C with a CaO value of 23.68 percent and SiO_2+Al_2O_3+FeO_2 of 61.22 per cent, following Indonesia National Standard Number 2460-2014[13] and ACI Manual of Concrete Practice 1994 parts. 1 226.3R-3 where there is a calcium (CaO) content of more than 10 per cent and the combined value of SiO_2+Al_2O_3+FeO_2 is 61.22 < 70. The mixtures used in this study were: fas 0.4 – s/p 1:075 – viscocrete 1003 of 0.7 percent [14] with dosage of fly ash are 5% and 15% of cement weight

2.1. Initial Research

Furthermore, a specific test was carried out to determine the initial description of the core temperature of the concrete and the mix design in this study for the casting of the 5 per cent based on previous experimental [15] and 15 per cent variation of fly ash preplaced method as comparison specimens, then cylinder conventional method with a mixed design based on SNI 03 2834 2000 [16] as conventional concrete. The cylinder size for the three test objects is 150 x 300 mm, with temperature monitoring starting from the completion of casting with technical checks for the first 24 hours every 2 hours. The detail of the preliminary test can be depicted in figure 3.

(a) Cylinder for 3 test objects (b) Temperature Monitoring

Figure 3. Preliminary Test on Temperature

2.2. Main Research

The main research of this experimental test is the utilizing partial fly ash and the concreting method for producing mass concrete specimens. There are two-stage for preparing the specimen of mass concrete. At the first, lay down the coarse aggregate in cube moulds (600mm x 600mm x 600mm) and then inject the grout with the variation of fly ash into moulds for fulfilling the void. Moreover, figure 4 show the specimens.

(a) Mass concrete (b) Temperature Monitoring

Figure 4. Mass Concrete Specimen

3. Result and Discussion

3.1. Initial test result

Before conducting research using large cube specimens, preliminary temperature testing was carried out on a 150 x 300 mm cylinder with a composition according to the mix design. The results of temperature in the initial test are shown in table 3.

Table 3. Temperature in the initial test

Time/Hour	Preplacedd Aggregate Concrete		Conventional
	Fly ash 5 %	Fly ash 15 %	
2	28.8	29.6	28.9
3	30.8	27.3	31.5
4	29.8	28.7	29.1
5	25.5	28.1	29
6	26.5	26.8	27.5
7	26.7	26.2	27.2
8	28.6	25.9	26.2
9	29.3	25.8	26.3
10	31	27.4	28.8
11	31.1	27.8	30.2
12	31.7	31.4	31.9

3.2. Conventional Method

The process of making mass concrete specimens with the conventional method is done by mixing all the ingredients according to the concrete-forming mix design at the same time in a mechanical mixing machine then inserting the concrete mixture into the mould.

Table 4. The temperature of Conventional Method

Time/Hour	Temperature The surface of Mass Concrete	The core of Mass Concrete	Ambient	Difference between surface and core
0	43.50	46.35	31	2.850
2	43.25	47.9	29	4.600
4	45.25	55.6	28	10.30
6	47.60	65.2	28	17.60
8	56.35	73.0	27	16.65
10	56.60	76.2	26	19.55
12	55.35	76.2	25	20.80
14	58.45	76.8	29	18.30
16	57.35	73.7	30	16.35
18	56.90	71.7	32	14.80
20	58.70	70.1	33	11.40
22	59.40	69.8	32	10.35
24	58.90	68.0	30	9.000

Monitoring the temperature that occurs during the first 24 hours after casting is very visible the difference between the surface and the concrete core is 58.9 C and 68 C while room temperature is 30 C. Comparison of Surface and Core Temperatures for 24 hours that the temperature that occurs within 12 hours of the completion of the mass concrete casting activity. there is a maximum temperature difference of 20.8 C between the surface and the concrete core. Based on ACI 207.1R-05 [3] the maximum temperature difference to avoid thermal cracking between the concrete core and the surface and core is

± 20°C. This shows that from the research there is a temperature difference that can cause thermal cracking, which can be shown in table 4.

3.3. Preplacedd Aggregate Method

Preplacedd aggregate concrete (PAC) is defined as concrete produced by placing coarse aggregate in the form and then injecting portland cement-sand. usually with an admixture. to fill voids by ACI Committee 116R. The implementation of preplaced aggregated concrete casting in these specimens can be shown in figure 5 and figure 6.

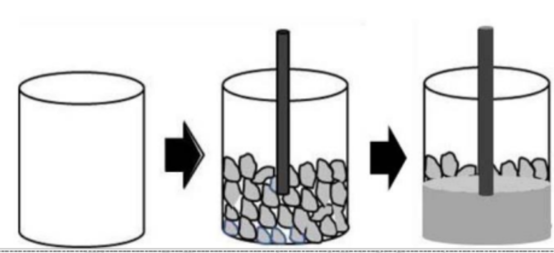

Figure 5. Preparation of PAC Specimens

Figure 6. PAC Specimens in Laboratory

3.3.1. Mix Design 5% of Fly ash

Monitoring the temperature that occurred within 24 hours. it was seen that there was an increase in surface and core temperatures after casting. namely 67.1 C for the core and 54.75 C for the concrete surface and the room temperature as control was 32°C. The temperature that occurred within 24 hours of the completion of the new mass concrete casting activity was seen an increase in temperature and a value ratio of 12.4°C between the surface and the concrete core. In the variation of Fly ash 5% to the total cement weight as a substitute for cement. the temperature is reduced from ± 20°C. The temperature of Preplaced Method for 5% Fly ash can be depicted in table 5

Table 5. The temperature of Preplaced Method for 5% Fly ash

Time/Hour	Temperature			The surface
	The surface of Mass Concrete	The core of Mass Concrete	Ambient	
0	44.60	45.35	32	0.75
2	45.15	45.90	32	0.70
4	45.20	46.80	31	1.60
6	46.45	48.90	30	2.40
8	49.45	52.50	29	3.10
10	52.05	58.50	28	6.40
12	56.45	64.60	27	8.10
14	58.65	67.30	26	8.60
16	57.70	69.00	29	11.3
18	57.15	68.70	31	11.6
20	56.20	67.60	33	11.4
22	54.35	66.40	33	12.0
24	54.75	67.10	32	12.4

3.3.2. Mix Design 15% of Fly ash

Monitoring the temperature that occurred within 24 hours. it was seen that there was an increase in surface and core temperatures after casting. namely 67.6 C for the core and 56 C for the concrete surface and the room temperature as control was 32 C. The temperature that occurred within 24 hours of the completion of the new mass concrete casting activity was seen an increase in temperature and a value ratio of 11.6 C between the surface and the concrete core. In the variation of Fly ash 15% to the total weight of cement as a substitute for cement. the temperature is reduced from ± 20°C. For more details on the difference in surface temperature and concrete core. The temperature of Preplaced Method for 15% fly ash can be shown in table 6 and figure 7.

Table 6. The temperature of Preplaced Method for 15% Fly ash

Time/Hour	The surface of Mass Concrete	Temperature The core of Mass Concrete	Ambient	The surface
0	46.2	45.1	31	-1.1
2	44.9	45.9	31	0.9
4	44.2	46.7	30	2.5
6	43.9	46.8	29	2.9
8	42.8	45.8	28	3.0
10	43.8	46.9	27	3.1
12	46.0	50.3	27	4.3
14	47.9	54.2	30	6.3
16	51.8	60.3	32	8.5
18	55.7	64	33	8.3
20	56.6	65.8	33	9.2
22	56.9	66.1	32	9.2
24	56	67.6	32	11.6

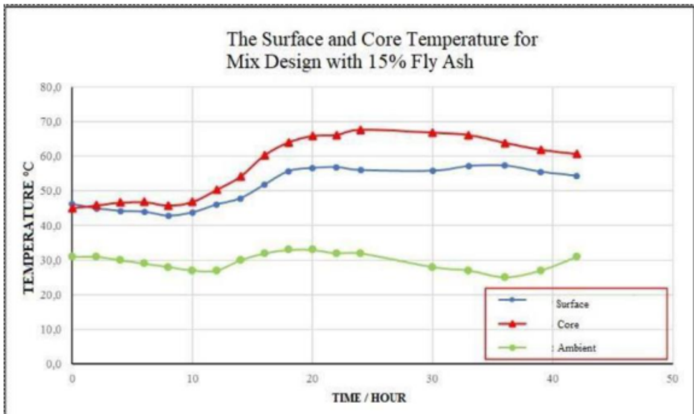

Figure 7. Temperature Graphic of Preplaced Method for 15% Fly ash

3.4. Surface Temperature

For monitoring the surface temperature of all test specimens in the first 24 hours. it is seen that there are differences that occur from the Conventional Method. Preplacing fly ash 5% and 15% of weight cement into mix composition of concrete can decrease temperature by 59.0 C, 54.8 C and 56.0 C respectively. The comparison for surface temperature for the specimens can be described in table 7.

Table 7. Comparison for Surface Temperature

Time/Hour	Surface Temperature		
	Conventional	Fly ash 5%	Fly ash 15%
0	43.5	44.6	46.2
2	43.3	45.2	44.9
4	45.3	45.2	44.2
6	47.6	46.5	43.9
8	56.4	49.5	42.8
10	56.6	52.1	43.8
12	55.4	56.5	46.0
14	58.5	58.7	47.9
16	57.4	57.7	51.8
18	56.9	57.2	55.7
20	58.7	56.2	56.6
22	59.4	54.4	56.9
24	59.0	54.8	56.0

3.5. Core Temperature

In monitoring the core temperature of all test specimens in the first 24 hours of the first day. it is seen that there are very differences that occur from the conventional Method. Preplacing fly ash 5% and 15% of weight cement into mix composition of concrete can decrease temperature of 68.0 C. 67.1 C and 67. 6 C respectively. This result is inversely proportional to the use of an increased percentage of fly ash. Moreover, the core temperature of the conventional method with normal concrete mixtures undergoes the hydration process more quickly at 12 hours after casting with a value of 76.2 C compared to the preplaced method and the addition of the percentage of fly ash. Core temperature at 12 hours after casting is 64.6^{o}C for 5% fly ash and 50.3^{o}C for 15% fly ash. However, the temperature of the preplaced method only increased in the first 24 hours after the casting was completed. This shows that increasing the percentage of fly ash to the total weight of cement used as a partial replacement of cement can delay the hydration time and reduce the differences temperature between surface and core temperatures so that there is no thermal cracking in the mass concrete. The comparison for core temperature for the specimens can be described in table 8.

Table 8. Comparison For Core Temperature

Time/Hour	Conventional	Core Temperature	
		Fly ash 5%	Fly ash 15%
0	46.4	45.4	45.1
2	47.9	45.9	45.9
4	55.6	46.8	46.7
6	65.2	48.9	46.8
8	73	52.5	45.8
10	76.2	58.5	46.9
12	76.2	64.6	50.3
14	76.8	67.3	54.2
16	73.7	69.0	60.3
18	71.7	68.7	64.0
20	70.1	67.6	65.8
22	69.8	66.4	66.1
24	68.0	67.1	67.6

3.6. Comparison of All Test Objects

From the results of testing the temperature of all mass concrete specimens between the conventional method and the pre-laid concrete method using 5% fly ash as a partial replacement of cement. the percentage value of the temperature decreased by 40% against the mass concrete temperature of the conventional method. and the use of 15% fly ash as a partial cement replacement percentage the temperature is 44% of the mass concrete temperature of the conventional method. Furthermore, increasing the percentage of fly ash, the temperature of the mass concrete decreases. The comparison of all specimens can be described in table 9.

Table 9. The Comparison of Test Objects

The object of Mass Concrete	Surface	Temperature Core	Difference	Percentage of Temperature Reduction
Conventional	55.35	76.2	20.8	0%
Fly ash 5%	54.75	67.1	12.4	40%
Fly ash 15%	56	67.6	11.6	44%

4. Conclusion

1. The temperature behaviour analysis of the preplaced mass concrete method can decrease and delay the increasing temperature of specimens compared to the conventional method.
2. Reduction temperature percentage for preplaced method with the use of fly ash 5% and 15% in the grout mixture are 40% and 44% compared to the conventional method.
3. The mass concrete temperature of three specimens are12.4^{o}C. 11.6^{o}C and 20.8^{o}C respectively. The maximum temperature increase with the use of fly ash 5% and 15% occurs in the first 24 hours, while the maximum temperature without fly ash within the first 12 hours.
4. The process of changing temperature of the conventional method tends to increase drastically which inversely with the preplaced method which the changes tend to be slow and gradual. It can affect the occurrence of thermal cracking processes where a gradual increase in temperature is considered to reduce the risk of cracking in the mass concrete due to differences in surface and core temperatures

5. Future Work

Research and development can be done to develop the idea of different timescales in the cooling process of mass concrete to find out more deeply the effect of mixing fly ash on temperature changes and prevention of thermal cracking.

References

[1] Nilson 1999 *Perencanaan Beton Bertulang* (Jakarta: Pradnya Paramitha)
[2] Tjokrodimulyo 2007 *Teknologi Beton* (Yogyakarta: Biro Penerbit Teknik Sipil dan Lingkungan. Gadjah Mada University)
[3] ACI 207.1R-05 2006 *Guide to Mass Concrete* (Detroit: American Concrete Institute)
[4] Patil A 2015 Heat of Hydration in the Placement of Mass Concrete *Int. J. Eng. Adv. Technol (India)* **4**
[5] ACI 209R-92 1997 *Prediction Temperature Affect in Concrete Structure* (Detroit: American Concrete Institute)
[6] Awal ASMA 1984 *Manufacture and Properties of Prepacked Aggregate Concrete* (Australia: M. Eng. Sc. Thesis. University of Melbourne)
[7] Awal ASMA and Shehu I 2015 Performance Evaluation of Concrete Containing High Volume Palm Oil Fuel Ash Exposed to Elevated Temperature. *Constr. Build. Mater*. pp. 214–220
[8] Lee Y, Choi MS, Yi ST and Kim JK 2009 Experimental Study on The Convective Heat Transfer Coefficient of Early-Age Concrete *Cem. Concr. Compos*. **31**. pp. 60–71
[9] ASTM C618 2010 *Standard Specification for Coal Fly ash and Raw or Calcined Natural Pozzolan for Use in Concrete* (ASTM International)
[10] Bayer I R 2004 *Use of Preplacedd Aggregate Concrete for Mass Concrete Aplication* (Turkish:A Thesis. Middle East Technical University)
[11] Awal A S M A, Ibrahim MHW, Mohd Ali AZ and Hossain MZ 2017 Mechanical Properties and Thermal Behaviour of Two-Stage Concrete Containing Palm Oil Fuel Ash *I. J. GEOMATE* **12**(32) pp 166-175
[12] Tuskaeva Z and Karyaev S 2020 Influence of Various Additives on Properties of Concrete *E3S*.

Web. Conf. **164**. 14007

[13] SNI 2460:2014 *Spesifikasi Abu Terbang Batu Bara Dan Pozzolan Alam Mentah Atau Yang Telah Dikalsinasi Untuk Digunakan Dalam Beton*. (Jakarta: Badan Standar Nasional)

[14] Chairunnisa N and Fardheny AF 2019 The Study of Flowability and The Compressive Strength of Grout/Mortar Proportions for Preplacedd Concrete Aggregate (PAC) *MATEC. Web. Conf.* **280**.04010

[15] Chairunnisa N, Nurwidayati R, Amaliya S H and Syifa Y 2020 Cement-Based Grout Mix Design for Preplacedd Aggregate Concrete Using Pozzolanic Materials *AIP. Conf. Proc* **2291**(1) 020030

[16] SNI 03-2834-2000 *Tata Cara Pembuatan Rencana Campuran Beton Normal* (Jakarta: Badan Standar Nasional)

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