“Comparison Study of Class F and Class C Fly Ashes as Cement Replacement Material on Strength Development of Non-Cement Mortar

by Arie Wardhono

IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Comparison Study of Class F and Class C Fly Ashes as Cement Replacement Material on Strength Development of Non-Cement Mortar

To cite this article: A Wardhono 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **288** 012019

IOP Conf. Series: Materials Science and Engineering **288** (2017) 012019 doi:10.1088/1757-899X/288/1/012019

Comparison Study of Class F and Class C Fly Ashes as Cement Replacement Material on Strength Development of Non-Cement Mortar

A Wardhono*

Department of Civil Engineering, Universitas Negeri Surabaya, Indonesia

*ariewardhono@unesa.ac.id

Abstract. Cement is the most widely used material for construction. However, the cement production has a negative impact on the environment, as it is one of the contributors to global warming. The production of one ton of cement also produces approximately one ton of CO_2. This encourages to the search for more environmentally friendly materials as cement replacement. The aims of this study are to compare two types of fly ashes, i.e. class F (high silicate, low calcium content) and class C (low silicate, high calcium content) fly ashes, as primary material on non-cement mortar. The strength test was performed at the age of 7, 14, and 28 days according to ASTM standard. Class C mortar was cured at ambient temperature, while class F was cured in ambient and $60^{O}C$ temperatures. The results show that class C fly ash non-cement mortar demonstrated a higher strength compared to class F fly ash at ambient temperature. In contrast, the class F fly ash non-cement mortars exhibited a better performance than class C when it cured at heat temperature. This might due to the high calcium content of class C fly ash which contribute to the additional hydration reaction on strength development.

1. Introduction

The use of Portland Cement (PC) as the primary material of concrete in construction industries has a negative issue on the environmental problems. The production of 1 ton of PC also produces approximately 0.8-1 ton of carbon dioxide (CO_2) gas [1-3]. This CO_2 gas is the main cause of the greenhouse effect that leads to the occurrence of global warming. This has led to the search for a new type of more environmentally friendly cement replacement material. One alternative material is the use of fly ash, a waste material from coal power plant.

The use of fly ash has been widely used as an additive, as well as a partial replacement of cement in order to improve its mechanical and durability properties [4-6]. According to ASTM standard, there are 3 types of fly ash, i.e. class F, class C and class N, based on its main content of the constituent material [7]. Class F and class C fly ashes are commonly used as cement partial replacement material due to its pozzolanic characteristics. The primary difference between class F and class C fly ashes is the Calcium (Ca) content where class F fly ash has Ca less than 10%, while Ca content in class C fly ash is higher than 10% [7].

As a material substitution, the use of 100% fly ash combined with alkaline activator may replace the role of cement in concrete or mortar. Previous research has shown that class F fly ash can be used as

100% cement replacement material due to its high silicate (Si) and aluminate (Al) content [8-9]. The reaction between Si, Al and the alkaline activator forms a geopolymer matrix through a polymerization reaction [10]. However, the main issue of using class F fly ash is the need for high temperatures to accelerate the geopolymer reaction to achieve its structural integrity during hardening process [11-13]. This might due to the low content of Ca in the class F fly ash raw material. In contrast, the high Ca content in class C fly ash forms a calcium-aluminate-silicate-hydrate (C-A-S-H) matrix rather than sodium-aluminate-silicate-hydrate (N-A-S-H) matrix in high Si class F fly ash. This C-A-S-H matrix has a similar behavior to alkali-activated material which has similar hydration products to that PC concrete but with a lower Ca/Si ratio. This leads to the ability of class C fly ash to be produced at ambient temperature [14-15]. Thus, the use of class C fly ash which has a higher Ca content (Ca > 10%) is assumed to be able to overcome the high temperature issue in the class F fly ash non-cement material.

This study presents the strength comparison between class F fly ash (high Si and Al content, low Ca content) and class C fly ash (high Ca content, low Si and Al content) non-cement mortar specimens. It will provide an insight on the comparison of strength development and the effect of Ca content between class F and class C fly ash. The strength property was measured by the compressive strength test at the age of 7, 14 and 28 days in accordance with ASTM standard [16].

2. Methods

2.1. Materials

Two types of fly ash, i.e. class F fly ash with high silicate (Si) and low calcium (Ca) content, and class C fly ash with low silicate (Si) and high calcium (Ca) content, were used to develop fly ash non-cement mortar specimens. The chemical composition for both class F and class C fly ash materials were identified by the X-Ray Fluorescence (XRF) test by PANalytical type Minipal 4 test equipment. The chemical composition of class F and class C fly ashes are shown in Table 1.

Table 1. The chemical composition of class F and class C fly ashes (mass %).

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	TiO_2	Mn_2O_3	SO_3
Fly ash class F	65.43	23.14	1.46	2.09	0.00	1.04	1.35	0.07	0.69
Fly ash class C	4.75	17.89	59.11	12.65	0.00	0.65	0.92	0.55	0.86

Fly ash (FF-1) in this research was class F fly ash. It had CaO of 2.09% (< 10%), the total SiO_2+Al_2O_3+ Fe_2O_3 of 90.03% (> 70%) and SO_3 of 0.69% (<5%) in accordance with ASTM C618 [7]. While, fly ash (FC-2) was categorized as class C fly ash with the CaO of 12.65%, the total SiO_2+Al_2O_3+ Fe_2O_3 of 81.75% (> 50%), and SO_3 of 0.86% (<5%). A mix of sodium silicate (SiO_2 to Na_2O ratio of 3.30) and sodium hydroxide (NaOH) were used as activators. 15 Molar NaOH and 12 Molar NaOH were used for class F and class C non-mortar cements, respectively, in accordance with previous research [17].

2.2. Mix design and proportion

The details of class F fly ash non-cement (FF-NC) and class C fly ash non-cement (CF-NC) mortars mix proportion are shown in Table 2.

Mix proportions of class F and class C non-cement mortars were developed from previous research [17, 19]. Mortar control specimen was developed in accordance with ASTM C109 [16] with a mass ratio of sand to binder of 2.75. However, due to a solid content on sodium silicate and NaOH, a water solid (w/s) ratio of 0.40 – 0.50 was used rather than a water binder (w/b) ratio. The total quantity of water in non-cement mortar specimens was determined as the sum of water in sodium silicate and NaOH, while the quantity of solid was calculated from the mass of the solid content in activator solution and fly ash [17].

Table 2. Mix proportions of class F and class C non-cement mortars

Mixture	Portland Cement	Class F fly ash	Class C fly ash	Fine sand	Sodium silicate	NaOH	Curing condition
FF-NC1	-	1.00	-	2.75	0.510	0.234	Ambient
FF-NC2	-	1.00	-	2.75	0.574	0.205	Ambient
FF-NC3	-	1.00	-	2.75	0.637	0.175	Ambient
FF-NC4	-	1.00	-	2.75	0.510	0.234	Heat 60^{O}C
FF-NC5	-	1.00	-	2.75	0.574	0.205	Heat 60^{O}C
FF-NC6	-	1.00	-	2.75	0.637	0.175	Heat 60^{O}C
CF-NC7	-	-	1.00	2.75	0.321	0.214	Ambient
CF-NC8	-	-	1.00	2.75	0.399	0.266	Ambient
CF-NC9	-	-	1.00	2.75	0.483	0.322	Ambient

Ambient (normal) curing temperature used for normal mortar was applied for non-cement class C mortars. Two types of curing temperatures, i.e. ambient curing temperature (for FF-NC1, FF-NC2, and FF-NC3 specimens) and heat curing temperature at 60^{O}C for 24 hours (for FF-NC4, FF-NC5, and FF-NC6 specimens), were applied for non-cement class F mortar.

2.3. Testing mortar specimens

The strength properties of class F and class C fly ash non-cement mortars in 50 x 50 x 50 mm^3 cube specimens were performed by compressive strength test in accordance with ASTM C109 [16]. Three mortar cubes were measured and tested at the age of 7, 14 and 28 days after casting.

3. Results and discussion

3.1. Strength development of class F fly ash non-cement mortar

Table 3 and Figure 1 give the strength development results reported for the FF-NC mortar specimens for all mixes curing at ambient temperature.

Table 3. Compressive strength of class F (FF-NC) mortar curing at ambient temperature

Mixture	Compressive strength (MPa) 7 days	14 days	28 days
FF-NC1	Failed to test	0.83 $\pm$ 0.13	1.25 $\pm$ 0.37
FF-NC2	Failed to test	0.72 $\pm$ 0.09	1.01 $\pm$ 0.24
FF-NC3	Failed to test	0.79 $\pm$ 0.18	1.19 $\pm$ 0.31

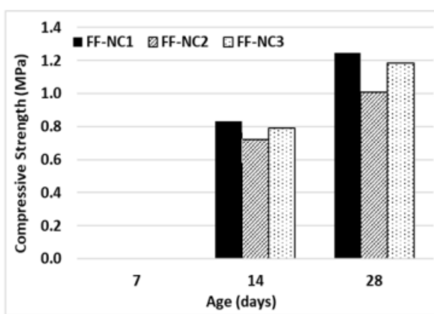

Figure 1. Compressive strength of class F (FF-NC) mortar curing at ambient temperature

The results show that the FF-NC mortar specimens failed to test at early age. This is attributed to the soft form of mortar specimens which indicated that the specimens were failed to achieve its structural integrity at 7 days' age. These results are in accordance with the previous research [19] which found that class F fly ash-based non-mortar specimens required high temperature during the curing process to achieve its structural integrity at early age. However, all mixes demonstrate a slight increase of strength throughout 28 days.

Table 4 and Figure 2 display the strength development results of FF-NC mortar specimens for all mixes curing at heat temperature at 60^{O}C for 24 hours.

Table 4. Compressive strength of class F (FF-NC) mortar curing at heat temperature (60^{O}C)

Mixture	Compressive strength (MPa)		
	7 days	14 days	28 days
FF-NC4	21.12 $\pm$ 1.36	22.58 $\pm$ 1.64	24.15 $\pm$ 2.31
FF-NC5	20.04 $\pm$ 1.74	20.22 $\pm$ 1.42	22.69 $\pm$ 1.94
FF-NC6	18.61 $\pm$ 1.59	19.28 $\pm$ 1.78	19.75 $\pm$ 2.18

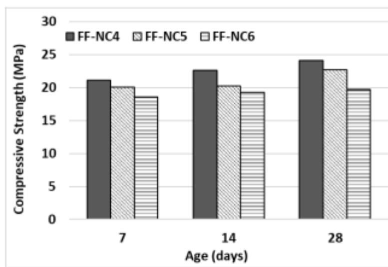

Figure 2. Compressive strength of class F (FF-NC) mortar curing at heat temperature (60^{O}C)

The strength development of FF-NC4 mortar specimen demonstrates the highest initial strength with 21.12 MPa (87.45% of final strength at 28 days) at 7 days followed by FF-NC5 and FF-NC6 with the strength of 20.04 MPa (88.32%) and 18.61 MPa (94.23%), respectively. This high initial strength was attributed to the high temperature (60^{O}C) during curing process for 24 hours which accelerate the reaction rate of non-cement mortar during the hydration process. A similar finding was also found by Bakharev [20]. The author found that high strength fly ash non-cement material can be achieved by heat curing treatment. FF-NC4 and FF-NC5 mortar mixes also display a significant increase from 7 to 28 days to 24.15 MPa (14.35% increase) and 22.69 MPa (13.24% increase), respectively.

Further, although FF-NC6 mortar exhibits the highest initial strength to the final strength ratio of 94.23%, it does not show any significant increase with time. This merely shows a slight increase of 6.16% in strength from 7 days to 28 days. This might attribute to the high silicate content from raw class F fly ash material and the activator (sodium silicate) content. According to Rowless and O'Connor [21], the strength of non-cement material (geopolymer) is affected by the silicate to aluminate ratio. It was found that higher Si/Al ratio than 2.5 leads to lower strength performance.

3.2. Strength development of class C fly ash non-cement mortar

Table 5 and Figure 3 show the strength test results of CF-NC mortar specimens for all mixes curing at ambient temperature.

Table 5. Compressive strength of class C (CF-NC) mortar curing at ambient temperature

Mixture	Compressive strength (MPa)		
	7 days	14 days	28 days
CF-NC7	12.55 $\pm$ 1.14	17.22 $\pm$ 1.72	18.13 $\pm$ 1.67
CF-NC8	9.63 $\pm$ 1.37	13.37 $\pm$ 1.58	13.78 $\pm$ 1.49
CF-NC9	8.74 $\pm$ 1.65	11.14 $\pm$ 1.85	12.11 $\pm$ 1.78

All CF-NC mortar specimens demonstrate a moderate initial strength with the strength of 8 MPa to 13 MPa at the age of 7 days. All specimens also show a significant increase in strength with the average increase of 38% at the age of 14 days, from 12.55 MPa to 17.22 MPa and 9.63 MPa to 13.37 MPa for CF-NC7 and CF-NC8, respectively. CF-NC7 and CF-NC8 mortar specimens also exhibit a significant continual improvement (43%) of strength throughout 28 days. Despite CF-NC9 shows the lowest strength in class C non-cement mortar with the strength of 8.74 MPa at 7 days' age, it still performs a constant increase of strength from 11.14 MPa and 12.11 MPa at the ages of 14 days and 28 days, respectively.

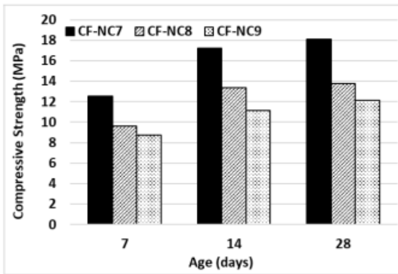

Figure 3. Compressive strength of class C (CF-NC) mortar curing at ambient temperature

Further, the strength of CF-NC7 mortar exhibits the highest initial strength in class C fly ash mortar with 12.55 MPa (69% of final strength) at 7 days' age. It displays a continual improvement of strength up to 28 days with the final strength of 18.13 MPa. In contrary, CF-NC9 mortar demonstrates the lowest strength development throughout 28 days. This might attribute to the high-water content in the activator of CF-NC9 mortar specimen.

3.3. Comparison of class F and class C fly ash non-cement mortar

Comparison of strength development of class F and class C fly ash non-cement mortar specimens for all mixes are shown in Figure 4. Figure 4(a) displays a comparison data between FF-NC and CF-NC specimens cured at ambient temperature, while Figure 4(b) shows a comparison data between FF-NC cured at high (60^{O}C) temperature and CF-NC cured at ambient temperature.

Class C non-cement mortar (CF-NC) demonstrates a higher compressive strength compared to class F (FF-NC) at ambient temperature as shown in Figure 4(a). FF-NC mortar also shows structural integrity failure at early age, although a small increase of strength is shown at 28 days' age. This is attributed to the calcium (Ca) content in the raw fly ash material. CF-NC mortar has a better Ca content (12.65%) than FF-NC mortar (2.09%). High Ca content forms C-S-H gel during hydration process, similar to that normal concrete, however with a lower Ca/Si ratio [22]. This allows CF-NC mortar to be produced at ambient temperature.

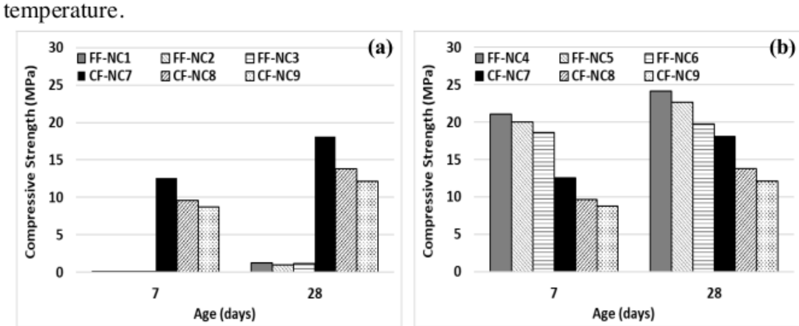

Figure 4. Comparison of class F and class C fly ash non-cement mortars. (a) Both class C and class F cured at ambient temperature, and (b) Class C cured at ambient temperature and class F cured at high (60^{O}C) temperature

In contrary, FF-NC with heat curing (60^{O}C) exhibits a better strength performance compared to CF-NC as shown in Figure 4(b). This suggests that high temperature plays an important role in the treatment of fly ash-based non-cement materials. This finding was corroborated by previous research [23]. According to the authors, heat curing treatment is significantly effective in developing the strength of fly ash-based non-cement (geopolymer) materials.

4. Conclusion

The strength development for class F fly ash and class C fly ash non-cement mortars were investigated experimentally from 7 to 28 days. The main conclusions may be drawn based on this study are:

- Class C non-cement mortar demonstrates a higher compressive strength compared to class F at ambient temperature due to the high calcium content in class C raw fly ash material.
- Class F non-cement mortars fail to achieve its structural integrity at ambient temperature.
- High temperature significantly affects the strength development of class F non-cement mortar.
- Class F non-cement mortar exhibits a better strength performance to that class C non-cement mortar at high temperature.

References

[1] Davidovits J 1994 *World Resource Review* **6** 2 263-278
[2] Meyer C 2009 *Cement and Concrete Composites* **31** 601-605
[3] Peng J Xia, Huang L, Zhao Y Bo, Chen P, Zeng L, and Zheng W 2013 *Advanced Materials Research* **610-613** 2120-2128
[4] Papadakis G Vagelis 1999 *Cement and Concrete Research* **29** 11 1727-1736
[5] Papadakis G Vagelis 2002 *Cement and Concrete Research* **32** 10 1525-1532
[6] Ahmaruzzaman M 2010 *Jurnal of Progress in Energy and Combustion Science* **36** 3 327-363
[7] ASTM Standard **ASTM C618**:2003
[8] Law D, Adam A, Molyneaux T, Patnaikuni I, and Wardhono A 2015 *Materials and Structures* **48** 3 721-731
[9] Gunasekara C, Setunge S, and Law D 2017 *ACI Structural Journal* **144** 3 743-752
[10] Davidovits J 1994 *Proc. 1st Int. Conf. on Alkaline Cements and Concretes (Kiev) (Kiev: Scientific Research Institute on Binders and Materials)* p 131-149
[11] Bakharev T 2005 *Cement and Concrete Research* **35** 6 1224-1232
[12] Pan Z and Sanjayan J 2009 *Journal of Materials Science* **44** 7 1873-1880
[13] Kong D and Sanjayan J 2010 *Cement and Concrete Research* **40** 2 334-339
[14] Natali A, Manzi S, and Bignozzi M 2011 *Procedia Engineering* **21** 1124-1131
[15] Nath P and Sarker P Kumar *Cement and Concrete Composites* **55** 2015-2014
[16] ASTM Standard **ASTM C109**:2003
[17] Deb P Sarathi, Nath P and Sarker P Kumar 2014 *Materials and Design* **62** 32
[18] ASTM Standard. ASTM C109:2003. *Standard test method for compressive strength of hydraulic cement mortars*. USA: ASTM International; 2003.
[19] Wardhono A 2015 *The Durability of Fly Ash Geopolymer and Alkali-Activated Slag Concretes* (Melbourne: Royal Melbourne Institute of Technology University)
[20] Bakharev T 2005 *Cement and Concrete Research* **35** 1224-1232
[21] Rowles M and O'Connor B 2003 *Journal of Material Chemistry* **13** 1161-1165
[22] Brough A R and Atkinson A 2002 *Cement and Concrete Research* **32** 6 865-879
[23] Winnefeld F, Leemann A, Lucuk M, Svoboda P and Neuroth, M 2010 *Construction & Building Materials* **24** 1086-1093

“Comparison Study of Class F and Class C Fly Ashes as Cement Replacement Material on Strength Development of Non-Cement Mortar

ORIGINALITY REPORT

10%	5%	9%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Papua New Guinea University of Technology Student Paper	4%
2	Submitted to Universitas Negeri Surabaya The State University of Surabaya Student Paper	2%
3	www.freepatentsonline.com Internet Source	1%
4	Submitted to University College Technology Sarawak Student Paper	1%
5	nisee.berkeley.edu Internet Source	1%
6	Submitted to Universiti Teknologi MARA Student Paper	1%
7	Qingbo Tian. "EFFECTS OF COMPOSITION OF FLY ASH-BASED ALKALI-ACTIVATED	1%

MATERIALS ON COMPRESSIVE STRENGTH: A REVIEW", Ceramics - Silikaty, 2020

Publication

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		