

Using Cementitious Materials Such as Fly Ash to Replace a Part of Cement in Producing High Strength Concrete in Hot Weather

Gidion Turuallo

Harun Mallisa

Civil Engineering Department, Tadulako University, Palu, Indonesia

turuallo@yahoo.co.uk

Abstract. The use of waste materials in concrete gave many advantages to prove the properties of concrete such as its workability, strength and durability; as well to support sustainable development programs. Fly ash was a waste material produced from coal combustion. This research was conducted to find out the effect of fly ash as a part replacement of cement to produce high strength concrete. The fly ash, which was used in this research, was taken from PLTU Mpanau Palu, Central Sulawesi. The water-binder ratio used in this research was 0.3 selected from trial mixes done before. The results of this research showed that the strength of fly ash concretes were higher than concrete with PCC only. The replacement of cement with fly ash concrete could be up to 20% to produce high strength concrete .

Keywords: Cementitious Materials; Sustainable Development; Fly Ash; High Strength Concrete and Workability

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1. Introduction

Concrete is the most widely used construction material because of its versatility, economy, and availability of raw materials, strength, and durability. Researchers are continuously working for improving the properties of concrete with the use of innovative chemical admixtures and supplementary cementing materials (SCMs). Furthermore, the use of SCMs in concrete can conserve energy and give environmental benefits as reduction in carbon dioxide emission as the result of decrease in Portland cement production.

Using supplementary cementing materials in concrete mixes will reduce cement contents, improve workability, increase strength and enhance durability of concrete [1-5]. The use of supplementary cementing materials (SCMs), which are by products such as fly ash, ground granulated blast furnace slag, silica fume, micro silica, and others will not only prevents them from being land-filled but also improve the properties of concrete in both fresh and hardened states [2, 6].

This research was conducted to find out the use of cementitious materials such as fly ash as a part replacement of Portland Composite Cement (PCC) to produce high strength concrete cured in hot

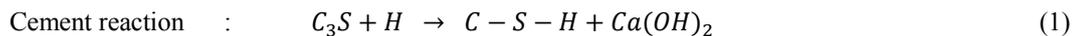


temperature. Fly ash is a by-product from burning pulverized coal in electric power generating plants. The size of fly ash particles is commonly finer than Portland cement, which it ranges from 10 to 100 micron [7, 8].

Some researchers [9-12] found that the strength development of fly ash concretes at early ages, which were cured under standard curing temperature (20⁰C); were slower when compared to the concrete with Portland cement only. In addition, Metha found that the pozzolanic hydration of fly ash cured at standard curing temperature started at 11-days after mixing and its contribution to the strength development of concrete appeared after 28-days [13]. However, the strength development of fly ash concrete at early ages especially for concrete with a lower water-binder, which were cured at elevated curing temperature (higher than standard curing temperature); were similar to that of concrete with Portland cement only [14, 15]. It is believed that this is due to the rate of pozzolanic reactions were increased as the increase of curing temperature. Large quantities of fly ash contributed a significant improvement of strength development of concrete.

2. Methodology/experimental work

The reaction of fly ash in hydration process is a secondary reaction. Fly ash reacts after the hydration process of cement. The silica in fly ash reacted with the calcium hydroxide (Ca(OH)₂), which is produced in the hydration of cement formed calcium silicate hydrate (C-S-H), which contributed to the strength development of concrete as the following reaction [2, 6]:



One of the benefits of using fly ash in concrete is that it can increase the workability of concrete. The replacement of cement with fly ash will increase the volume of cementitious materials in mixture. The increase of paste volume in concrete results in a reduction in aggregate particle interference and it will also increase the workability of concrete [9, 16]. The mix proportion of concrete was calculated based on the Modified Maximum Density Theory [17].

2.1. Materials

A single batch of sand, coarse aggregate, PCC cement, and fly ash were used throughout the experimental work. The sand was taken from Palu River, while the coarse aggregate was a crushed aggregate, which was taken from Loli; with a nominal size ranging from 5 to 20 mm. The superplasticizer was Type Naptha 511P, while fly ash was from PLTU Mpanau Palu, which is categorized as Class F fly ash with chemical composition as shown in Table 1 below:

Table 1 Chemical composition of fly ash taken from PLTU Mpanau Palu

Chemical compounds	Percentage by weight
SiO ₂	51,55
Fe ₂ O ₃	25,54
Al ₂ O ₃	17,26
CaO	2,09
K ₂ O	1,23
TiO ₂	0,95
MnO	0,48
Others	0,90

The absorption, density, sieve analysis, and the maximum void content of both coarse and fine aggregates were measured. The sand is in air dry conditions; therefore, some water was added for absorption to meet the saturated service dry (SSD) condition of the sand; similar for the coarse aggregate. The PCC cement was produced by PT Semen Tonasa, which is Type I cement with the specific gravity of 3.1.

2.2. Mix proportion

The mix proportion of concretes was calculated using the Modified Maximum Density Theory (MMDT), where the measurement of void content and proportion of sand to the total of aggregates are 23.25 % and 35% respectively. These gave the volume of paste and total aggregates were 0.273 and 0.727 respectively. The calculation of mixes with water-binder ratio of 0.30 are presented in Table 2 below:

Table 2. Calculated mix proportion of concrete

Material	Weight of materials per m ³ concrete (kg)				
	Percentage of fly ash, w/b = 0.30				
	0	10	15	20	25
Cement	437.713	393.942	372.056	350.170	328.285
Fly ash	-	43.771	65.657	87.543	109.428
Sand	688.900	688.900	688.900	688.900	688.900
Coarse aggregate	1256.00	1256.00	1256.00	1256.00	1256.00
Water	126.698	126.698	126.698	126.698	126.698
Superplasticizer	0.119	0.119	0.119	0.119	0.119

2.3. Specimen

The water-binder ratio that was taken in calculating mix proportions was 0.30. There were five mixes prepared, which were referred to the percentage of fly ash replacing cement in concretes, i.e. 0, 10, 15, 20, and 25%. The specimens for compressive strength test were cube with the size of 150mm x 150mm x 150mm. Three cubes were prepared for each testing age. The testing ages were 1, 3, 7, 21, and 28-days to find out the strength development of concretes.

3. Results and discussions

As described above, the percentage of fly ash to replace a part of cement were 0, 0.10, 0.15, 0.20 and 0.25 with the symbols of PCC, 10FA, 15FA, 20FA and 25FA respectively. The strength developments of concrete were investigated up to 28-days, which can be seen in Table 3 below:

Table 3. Strength development of concretes Concrete ages

Mix	3-days		7-days		21-days		28-days	
	Weight (kg)	Strength (MPa)						
PCC	8.823	36.366	8.814	57.689	8.824	60.644	8.820	62.478
10FA	8.803	36.267	8.768	57.244	8.846	58.178	8.868	60.267
15FA	8.601	42.044	8.841	56.800	8.858	59.956	8.862	66.756
20FA	8.768	43.733	8.650	52.444	8.862	57.644	8.872	61.556
25FA	8.781	39.289	8.739	45.111	8.860	54.844	8.874	56.622

Table 3 above shows that the strength of fly ash concretes at three days are similar to that of PCC concrete, even the strength of concretes with replacement fly ash above 15% have strengths higher than that of PCC concrete. This proves that there is no delay in strength gain of fly ash concrete at early ages (three days) with replacement cement levels up to 25%. At 28-days, the strength of concrete with 15% fly ash is higher 6.8% above the strength of concrete with PCC only, and it is like to continuously increase. It is believed as the results of the curing temperature above of the standard curing temperature (20⁰C) applied in Europe and America. It means that the use fly ash in concrete is suitable in counties with hot weather such as Indonesia. The strength of fly ash concrete obtained, however, are lower than that of fly ash concrete obtained in Europe and America with the same water-binder ratio. This is caused the used PCC has already mixed with pozzolanic materials in clinker.

4. Conclusions

Results of this research can be concluded as follow:

1. The slump of concrete mixes increased as the percentage of fly ash in concrete increased, even when using fly ash of 25%; the slump is collapse as the concrete flows.
2. The maksimum levels of fly ash for cement replacement to produce high strength concrete is 20%.

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