EFFECT OF CHEMICAL CHARACTERISTICS ON FLY ASH ON COMPRESSIVE STRENGTH OFHIGH-VOLUME FLY ASH CONCRETE (HVFAC)

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Abstract - The use of fly ash in concrete mixtures continues to be developed in the construction industry. In addition to aiming to utilize waste from coal combustion at the steam power plant, its use can also reduce CO_2 emissions caused by cement production activities. An example of its use is in producing high-volume fly ash concrete (HVFAC) with the addition of chemical admixture. Several studies have been carried out to determine the optimal mix design composition with the results indicating that satisfactory compressive strength of HVFAC is strongly influenced by the type and chemical characteristics of fly ash used. Therefore, this research aims to analyze the effect of chemical characteristics on fly ash on the compressive strength of HVFAC at 3, 7, 14, 28, and 56 days using the experimental method. The specimens were made with three variations, one of the normal concrete mixture using 100% Ordinary Portland Cement (OPC) as a control specimen, while the other two are of the HVFAC mixture comprising blended cement (20% OPC + 80% fly ash) from different sources. The comparison (M0), HVFAC-1 (M1) and HVFAC-2 (M2) mixtures used 100% OPC, OPC+fly ash A, and OPC+fly ash B, respectively. The results showed that the compressive strength of all HVFACs at all ages was lower than normal concrete with M2 having a higher compressive strength than M1 at 3, 7, and 14 days. However, at 28 and 56 days, the reverse was the case, thereby indicating that fly ash's chemical characteristics affect concrete's compressive strength at its Al_2O_3, SiO_2, and CaO contents.

Keywords - HVFAC, Fly Ash, Chemical Characteristic, Compressive Strength.

I. INTRODUCTION

The construction industry has continuously utilized fly ash in concrete mixtures to reduce CO_2 emissions caused by cement production activities and waste from coal combustion at the steam power plant. An example of its use is in producing high-volume fly ash concrete (HVFAC) through the provision of additional materials in the form of chemical admixture. Fly ash is used as a supplementary cementitious material (SCM) in concrete production and contributes to the hardening properties of Portland cement through hydraulic and pozzolanic activities [1]. This constituent is used in concrete to achieve energy conservation as well as economic, ecological, and technical benefits. Furthermore, it is used as a pozzolanic mineral mixture to produce better concrete properties, such as increased workability, compactness, pumpability, strength, durability and decreased water requirements, permeability, and corrosion potential [2]. The performance of fly ash in concrete is strongly influenced by its physical, mineralogy, and chemical properties. The mineralogy and chemical composition are highly dependent on the properties of the coal, while the combustion conditions in the power plant can also affect the properties of fly ash [1].

ASTM C618-12 [3] classified fly ash based on its chemical composition into three categories, namely classes N, F, and C. N and F have a minimum content of SiO_2, Al_2SO_3, and Fe_2O_3 compounds of 70%, while C is between 50 %-70%. Other chemical requirements specified in the ASTM C618 specification for Classes C and F fly ash include sulfur trioxide SO_3, moisture, and Loss of Ignition with maximum content values of 5.0%, 3.0%, and 6.0%. The ASTM C618 specification also describes the requirements for the physical specification, which was evaluated according to the ASTM C311-11b Standard Test Method for sampling and testing fly ash or natural pozzolans for use in concrete [4]. These include smoothness, strength activity index at 7 and 28 days of age, water requirement, soundness, and density uniformity.

According to ACI 232.2R [5], HVFAC contains at least 50% of the total mass of its binder in its mixture. In the application of self-compacting concrete, HVFA mixture with fly ash up to 90% of the total cementitious has been developed and used commercially. Cross et al. [6] stated that it is possible to produce acceptable concrete with a 100% fly ash binder for the highly reactive types. This HVFAC mixture can increase workability, strength, durability, pumpability, and thermal properties.

Additives or admixtures are materials added to the concrete mixture to improve its performance. It is generally divided into chemical and mineral additives. Chemical admixtures are used to change the characteristics of fresh concrete, guarantee its quality during mixing, delivery, casting, and maintenance, and overcome certain crises that may arise amid the construction process while reducing production costs. According to ASTM Standard C494 [7], this type of admixture is grouped into seven types in line with their characteristics and functions.

The curing of concrete is one of the most important stages after casting, carried out to ensure that the hydration reaction of cement compounds, including additives or substitutes, can take place optimally. Furthermore, it is also used to prevent excessive shrinkage, resulting in rapid or non-uniform moisture loss causing cracks.

This research aims to analyze the effect of chemical composition on fly ash on HVFAC performance using the water submerged curing (WSC) method in the laboratory. The specimens were made with three variations, one of the normal concrete mixture using 100% ordinary portland cement (OPC) as a control specimen, while the remaining two are of the HVFAC mixture using blended cement (20% OPC + 80% fly ash) from different fly ash sources. The first (M0), second (M1) and third (M2) mixtures used 100% OPC, OPC+fly ash A, and OPC+fly ash, respectively. The workability and compressive strength tests were conducted on fresh and hard concrete at the ages of 3, 7, 14, 28, and 56 days in cylindrical specimens measuring 100 mm x 200 mm submerged in water.

II. MATERIAL AND METHODE

Physical and Chemical Characteristics of Cement and Fly Ash

The physical characteristics of portland cement and fly ash were tested to obtain their properties as a basis for designing the composition of the concrete mixture. The test of chemical characteristics aims to analyze their chemical composition with the resulting mixture in accordance with the needs of the casting. This process was conducted by testing XRF (X-Ray Fluorescence) to determine the chemical content of the tested material in the form of its constituent elements used to produce HVFAC. Tables 1 and 2 show the results of testing the physical and chemical characteristics of ordinary portland cement (OPC) and fly ash whose quality greatly affects the manufactured concrete.

Based on the results of testing the physical characteristics of OPC in Table 1, it can be seen that the portland cement used meets the ASTM C150 specification [8]. This type of cement has been used previously in research on foam concrete with good performance results [9] [10].

PARAMETERS	Unit	Results	
		FA-A	FA-B
SiO_2	% wt	50.28	28.51
Al_2O_3	% wt	26.08	11.32
Fe_2O_3	% wt	6.25	24.66
CaO	% wt	5.93	21.15
MgO	% wt	2.68	9.27
Na_2O	% wt	3.43	0.54
K_2O	% wt	0.84	0.88
TiO_2	% wt	0.91	0.62
MnO_2	% wt	0.13	0.38
P_2O_5	% wt	0.27	0.17
Cr_2O_3	% wt	0.01	0.01
SO_3	% wt	0.98	1.90
Loss On Ignition	% wt	1.85	0.06

Table.1Characteristics of OPC

Figure 1 shows the physical appearance of each fly ash used in this research. It was taken from two different sources of power plant units, namely FA-A from steam power plant Cilacap Indonesia 2x300 MW, and FA-B from steam power plant Cilacap Indonesia 1x600MW.

Figure 1: Fly ash

Table 2 illustrates that each fly ash has different chemical characteristics. According to ASTM C618-12 which classifies fly ash based on the total content of SiO_2, Al_2SO_3, and Fe_2O_3. FA-A is categorized in class F with a total content of 82.61%, while FA-B is classified as class C of 64.49% ((but contains high CaO, namely 21.15%).

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Table.2Chemical characteristics of fly ash

Physical Characteristics of Aggregates

Table 3 shows the physical characteristics of coarse and fine aggregates. The coarse aggregate used is crushed stone, obtained from a stone crusher using raw materials originating from Bili-bili, Gowa Regency, South Sulawesi. Its visible physical characteristics are in accordance with the specifications of ASTM C33 [11].

The fine aggregate is silica sand from the Pinrang river, South Sulawesi and its physical characteristics meet the ASTM C33 specifications, as shown in Table 3.

Properties	Coarse Agg	Fine Agg
Colloid Content [%]	0.76	4.80
Fineness Modulus	6.99	3.01
Water absorption [%]	1.20	3.02
Specific Gravity (SSD)	2.61	2.58

Table.3Physical Characteristics of aggregate

The chemical admixture used in this research is a type E chemical admixture based on modified polycarboxylate in water. It has the function of reducing and accelerating the absorption of water and lowering the amount of mixing water needed to produce concrete with a certain consistency, thereby accelerating the initial setting.

Mixed Design

This research was carried out using a mixed design consisting of three variations of the portland cement and fly ash. The test specimens for the first mixed variation comprise normal concrete using 100% OPC as a control specimen, while the remaining two are of HVFAC mixture with blended cement (20% OPC + 80% fly ash) from different fly ash sources. The first (M0), second (M1), and third (M2) mixtures used 100% OPC, OPC+fly ash A, and OPC+fly ash B, respectively.

Concrete Test

Specimen testing was carried out on both fresh and hard concrete. For fresh concrete testing, the slump flow test was conducted according to the ASTM C1611 standard [12], as shown in Figure 2 with the following procedure: (a) Place a base plate on a flat and level surface that does not absorb water. (b) Moisten the slump test mold and the bottom surface with water. (c) Gradually fill the mold in an inverted position with the concrete mix until it is full. (d) Level the surface of the mixture on the top side of the mold. (e) Lift it slowly as far as 225 ± 75 mm in 3 ± 1 second with a steady upward lift without lateral movement or twisting, and complete the entire test from initial filling to uninterrupted mold release within 2½ minutes. (f) After the mixture stops flowing, the maximum and minimum diameter lengths are measured. The average slump flow value was calculated using equation (1):

Slump Flow $= (d1 + d2)/2$……….……… (1)

d1: the largest diameter of the circular spread of the concrete (cm)
d2: the circular spread of the concrete at an angle approximately perpendicular to d1 (cm).
For hard concrete testing, the compressive strength test was carried out at 3, 7, 14, 28, and 56 days in the form of a cylindrical specimen measuring 100 mm x 200 mm which had been examined with water submerged curing. The compressive strength test of the specimen is carried out with a compression test apparatus as shown in Figure 3, with the procedure referring to ASTM C39 [13].

Figure 2: Slump flow tested

Figure 3: Compressive tested

Strength Activity Index (SAI)

The Strength Activity Index (SAI) is based on a compressive strength test performed on a mortar cube specimen made by partial replacement of cement with fly ash (blended cement) [14]. The specimens were cured in water for testing at 3, 7, and 28 days and the results were compared with the control mortar. The SAI test procedure follows the ASTM C311 standard, which can be calculated using Eq. 2.

SAI = A/B x 100 ………………………….(2)

A: average strength of blended cement
B: average strength of control mortar OPC;

III. RESULTS AND DISCUSSION

Mix Design HVFAC

The design of the concrete mix made in this research consisted of three variations as shown in Table 4:

Code	OPC (kg)	FA-A (kg)	FA-B (kg)	C. Agg (kg)	F. Agg. (kg)	Water (ltr)	Admix (ltr)
M0	532	0	0	750	870	83	10.6
M1	106	426	0	750	870	83	10.6
M2	106	0	426	750	870	83	10.6

Table.4 HVFAC Composition (per 1 m^3)

Fresh Concrete Test Results

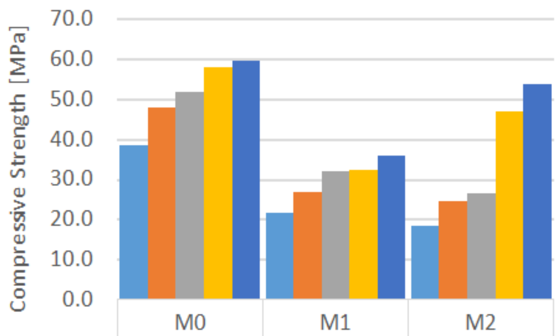
The workability test was carried out with the slump test on fresh concrete according to the ASTM C143 standard to determine the average results on each specimen as shown in Table 5. Based on the average value, it can be concluded that all mixtures meet the criteria as Self Consolidation Concrete (SCC) [15]. Visual observation of fresh concrete on M0 shows that the mixture is homogeneous, slightly stiff, and slightly bleeding, while on M1 it is homogeneous, stiff, and does not bleed. Finally, on M2 the mixture is homogeneous, slightly stiff, and bleeding.

Specimens	Slump (Cm)		
	d1	d2	Average
M0	76	64	70
M1	74	68	70
M2	74	72	73

Table.5 Slump flow results

Hard Concrete Test Results

Figure 4 shows the compressive strength of the specimens at the age of 3, 7, 14, 28, and 56 days for each variation. The compressive strength test results for M0 are (MPa) 38.9, 48.2, 51.8, 58.1, and 59.8. Meanwhile, M1 is (MPa) 21.8, 26.9, 32.1, 32.4, and 36.0, while M2 is (MPa) 18.5, 24.6, 26.9, 47.2, and 53.8. Based on the figure, all HVFAC compressive strength values of M1 and M2 are lower than M0.



	M0	M1	M2
3 day	38.9	21.8	18.5
7 day	48.2	26.9	24.6
14 day	51.8	32.1	26.9
28 day	58.1	32.4	47.2
56 day	59.8	36.0	53.8

Figure 4: Compressive strength results

At 3, 7, and 14 days, the compressive strength of M1 was higher than M2, but at 28 and 56 days, the reverse was obtained. The increase in compressive strength from 28 days to 56 days at M0, M1, and M2 were 1.7 MPa or 2.9%, 3.6 MPa or 11.0%, and 6.6 MPa or 14.0%.

Strength Activity Index (SAI) Results

From Table 6, it is observed that the substitution of 80% cement by fly ash B (FA-B) showed an increase in the ratio of the strength activity index, which was designated as M2 (0.81) at 28 days. The strength activity index at M2 (0.81) observed that the substitution of 80% cement with FA-B showed an increase in the strength activity index ratio after 28 days. This is because the substitution of 80% cement with FA-B shows a strong reaction from the C-S-H gel arrangement. As per ASTM C618-12a [3], Strength Activity Index(SAI) for fly ash and natural pozzolan must be >0.75(75%) at 28 days.

Specimens	Strength Activity Index (SAI)				
	3 day	7 day	14 day	28 day	56 day
M0	-	-	-	-	-
M1	0.56	0.56	0.62	0.56	0.60
M2	0.50	0.51	0.52	0.81	0.90

Table.6 Strength Activity Index (SAI) results

IV. CONCLUSION

Based on the results, the following conclusions were made:

a) All mixtures showed behavior as Self Consolidation Concrete (SCC).
b) The compressive strength values of all HVFAC were lower than the comparison specimens at all ages of concrete.
c) The content of SiO_2 and Al_2O_3 in fly ash affected the initial compressive strength of concrete at the age of 3, 7, and 14 days. The higher the amount of class Ffly ash content, the greater the initial compressive strength.
d) The CaO content in fly ash affects the compressive strength of concrete at 28 and 56 days. The higher the CaO content (class C fly ash), the greater the compressive strength at 28 and 56 days.
e) In concrete without fly ash, the increase in compressive strength from 28 to 56 days is very small, namely 2.9%. Meanwhile, in HVFAC, the increase was quite significant, namely 11.0% - 14.0%.
f) Class C fly ash showed a higher strength activity index (SAI) ratio after 28 days age of HVFAC.

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