Compressive Strength of High-Volume Fly Ash (HVFA) Concrete as a Function of Lime Water and Curing Time

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Research Article

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Abstract

The compressive strength of high-volume fly ash (HVFA) concrete with varied volume percentages of 40%, 50%, and 60% was examined utilizing low calcium fly ash (Class-F) as a partial replacement for regular Portland cement in this study. On the 7th, 28th, and 56th days, the compressive strength is tested. At the 7th and 28th days, the influence of saturated lime water on the compressive strength of HVFA concrete is evaluated. The inclusion of fly ash as a replacement for Portland cement reduces the compressive strength of the HVFA concrete, according to the findings. At the 56th day, the HVFA concrete with 40% fly ash substitution has a compressive strength equivalent to the regular weight concrete. At the 28th day, it was discovered that saturated lime water was helpful in maximizing the strength of HVFA concrete with 50% fly ash substitution. There was additional information about the characterization of HVFA concrete.

1.0 Introduction

Fly ash has been widely used in the concrete industry, particularly in the manufacture of concrete, for many years in various nations, but not in Malaysia. Furthermore, due to a lack of research and development linked to industry standards both worldwide and locally, the amount of fly ash utilized as a substitute in Portland cement is relatively tiny. Furthermore, the use of more than 30% fly ash to substitute Portland cement in such a large volume in the construction of high-volume fly ash (HVFA) concrete is not widely used and implemented, particularly in Malaysia. The unpredictability of the compressive strength was one of the primary factors limiting the use of HVFA concrete at various percentages of fly ash substitution in real building. Furthermore, the lack of fundamental understanding, research, and development HVFA concrete, particularly in Malaysia, was exacerbated by the application of obsolete local and international standards for benchmarking.

Concrete is also recognized as one of the most important core materials in the current building industry. Concrete is becoming more popular every year because of its simplicity of casting and durability. Despite the tangible benefits it offered, it nevertheless had several flaws. It was discovered that the principal binder ingredient of concrete, Portland cement, is one of the major contributors to carbon dioxide emissions [1]. A ton of carbon dioxide is emitted into the atmosphere for every tons of Portland cement produced [2]. The greenhouse effect, which increases global warming, would be induced by an increase in carbon dioxide content in the atmosphere. Researchers came up with the notion of using fly ash as a complete or partial substitution material for Portland cement, which is also one of the answers to this problem.

Most of the current research on geopolymer concrete has shown that full substitution of Portland cement with fly ash in concrete is possible. The geopolymer concrete, on the other hand, has several faults and limits. Geopolymer concrete has two main drawbacks, particularly in terms of building strength at a young age: it requires careful chemical control during casting and heat for curing [3]. Because of these two significant disadvantages, geopolymer concrete is only appropriate for pre-casting and not for in-situ

casting. As a result, HVFA concrete, which uses fly ash as a partial replacement ingredient for Portland cement, offered as a new green concrete material. Unlike geopolymer concrete, HVFA concrete contains a minor quantity of Portland cement whereas the bulk of the Portland cement is replaced by fly ash. The purpose of keeping a small quantity of Portland cement in HVFA concrete is to help with early strength development and to allow for the formation of calcium hydroxide during the cement hydration process to activate the pozzolanic reaction of fly ash.

HVFA concrete, unlike geopolymer concrete, does not require an additional alkaline solution to activate the pozzolanic reaction of fly ash. Furthermore, HVFA concrete does not require heat for curing while keeping the same quantity of fly ash as a replacement for Portland cement, allowing it to compensate for the lack of strength at an early age [3]. However, during the development of HVFA concrete at various percentages of fly ash, the compressive strength remained a major concern. Despite the presence of some OPC, the strength of HVFA concrete at an early age was found to be lower than that of NWC [4]. The practical uses of the HVFA might likewise be called into doubt. As a result, the purpose of this study is to gain a better knowledge of the compressive strength development of HVFA concrete with 40%, 50%, and 60% fly ash in place of Portland cement. Furthermore, for the compressive strength of HVFA concrete, the optimum impact of saturated lime water on the 7th and 28th days was observed. The morphological, chemical composition, and functional groups involved in HVFA concrete were further studied using a scanning electron microscope (SEM), energy dispersive x-ray spectroscopy (EDS/EDX), and Fourier transform infrared spectroscopy (FTIR).

2.0 Fly Ash As Replacement For Portland Cement For Hvfa Concrete

Cement hydration, according to Papadakis [5], is a process in which water is added to powdered cement to create calcium silicate hydrate (C-S-H) gel (Chemical Reaction (1)). As a result of the cement hydration reaction, a specific hydroxyl group, namely calcium hydroxide, would be liberated.

Calcium hydroxide is produced during the cement hydration process because of the presence of water, which might function as an activator for the pozzolanic reaction of fly ash. The pozzolanic reaction of fly ash produces calcium silicate hydrate (C-S-H) gel, which controls the cementitious characteristics of concrete (Chemical Reaction (2)) [6].

After 3 days of being combined with the cement mixture, the pozzolanic reaction of the fly ash would begin [5]. The pozzolanic process, in comparison to the cement hydration reaction, is thought to take longer to complete [7, 8]. According to ASTM C618-19 [9], there are two types of fly ash: high calcium fly ash (Class C) and low calcium fly ash (Class A) (Class F). Table 1 [6] shows the calcium concentration of fly ash for both Class C and Class F.

Table 1
Calcium content in Class C and Class F fly Ash.

Types of Fly Ash	Calcium Content
Class C	$\geq 8\%$ Calcium oxide (CaO)
Class F	$< 8\%$ Calcium oxide (CaO)

One of the most significant distinctions between Class C and Class F fly ash was that Class C had some cementitious characteristics before experiencing the pozzolanic reaction, but Class F had to rely exclusively on the pozzolanic reaction to get cementitious capabilities [6]. It has also been demonstrated that concrete containing high calcium fly ash (Class C) reacts faster and develops higher early-age strength than concrete containing low calcium fly ash (Class F) [10]. However, as compared to Class F fly ash, Class C fly ash has a weaker resistance to sulphate attacks and less suppressing capacity for alkali-silica growth [11, 12]. One of the primary benefits of HVFA concrete, according to Rashad [13] and Kim et al. [14], was its resistance to sulphate attack. The high calcium fly ash Class C, on the other hand have a negative impact on these HVFA concrete's most important characteristics. As a result, Class C fly ash should not be used in HVFA concrete casting.

Siddique [15] shown that increasing the fly ash replacement ratio from 40–50% resulted in a decrease in the compressive strength of HVFA concrete. It has also been observed that after one year of curing, the compressive strength of HVFA concrete cannot exceed that of OPC concrete. Padurangan et al. [16] conducted a similar experimental investigation on HVFA concrete with varied fly ash replacement percentages of 55%, 65%, 75%, and 85%. The results showed that HVFA concrete with a greater percentage of fly ash replacement have a slower compressive strength development than HVFA concrete with 55% and 65% fly ash replacement. At the 28th day, HVFA concrete with 75% and 85% fly ash replacement were able to surpass the compressive strength of OPC concrete, but HVFA concrete with 75% and 85% fly ash replacement were not. Both Siddique [15] and Padurangan et al. [16] found that increasing the fly ash replacement percentage causes the compressive strength of HVFA concrete to grow more slowly. When comparing the results of Siddique [15] and Padurangan et al. [16], however, there was a discrepancy. At the 28th day, HVFA concrete with 40% and 50% seen by Siddique [15] was unable to overcome the compressive strength of OPC concrete, but HVFA concrete with 55% and 65% observed by Padurangan et al. [16] was able to surpass the compressive strength of OPC concrete. This contradicts the conclusion drawn from both findings. One probable source of this discrepancy is the use of different binder materials (cement and fly ash) in concrete mixtures for both studies, which have distinct chemical reactions. Another explanation for this phenomenon might be the presence of an optimal fly ash replacement percentage, which is anywhere between 40% and 65%. As a result, more study should be focused on replacing fly ash in the range of 40–65%, while keeping the same quantity of binder material (cement and fly ash). This is to see if the inferred connection from the findings is correct or if there is an ideal proportion of fly ash substitution.

For the cement hydration process to be completely active, the water to binder ratio was found to be 0.22 to 0.25 [17]. In the past, an excess amount of water was added to the concrete mix to make it workable. Wang and Park [4] and Sarika et al. [18] found that when the water to binder ratio surpasses a specific threshold value, which changes depending on the amount of fly ash replacement, the compressive strength of HVFA concrete cannot surpass that of OPC concrete on the 28th day. As lime water is a diluted form of calcium hydroxide, a low water to binder ratio was required to get a better compressive strength. With 50% ultra-fine fly ash substitution, the impact of utilizing saturated lime water in concrete casting was shown to be beneficial in improving the 28th day compressive strength of HVFA concrete [14]. On HVFA concrete cast with raw fly ash, however, the increase in strength was less noticeable [14]. According to Tahir and Chaudhry [19], mixing alkaline liquid with lime in fly ash concrete does not enhance the compressive strength of 25%, 35%, or 50% fly ash concretes, but rather decreases it. Heat and water curing was a typical curing process for HVFA concrete. Heat curing was shown by Yazici et al. [20] to be beneficial in increasing first-day compressive strength but decreasing long-term compressive strength of HVFA concrete. On the other hand, HVFA concrete that is water cured had a lower compressive strength on the first day compared to OPC concrete, but the difference became less noticeable by the third day. The cement hydration process in HVFA concrete is favored when the curing temperature is less than 35°C [21]. When the curing temperature is approximately 50°C, however, the cement hydration process is inhibited and the pozzolanic reaction is favored within the HVFA concrete [21].

As a result, it was determined that additional study on HVFA concrete should be undertaken to fill up the information gaps. The discrepancy between Siddique [15] and Padurangan et al. [16] findings must be resolved via study. Aside from that, there is only a small amount of study on the influence of saturated lime water on the compressive strength development of HVFA concrete with a 40–60% fly ash replacement. As a result, the purpose of this study was to address the highlighted research gaps.

3.0 Methodology

3.1 Materials

Sejingkat Coal Power Plant in Kuching, Sarawak, provided low calcium fly ash (Class F). Cahaya Mata Sarawak produced the Portland cement utilized in this investigation (CMS). Kasuma Engineering Sdn. Bhd. supplied the river sand and crushed rocks for the project. Sand and broken rocks had diameters ranging from 150µm to 5mm and 5 to 20 mm, respectively. According to BS 12620:2002 [22], the sand grading curve and the particle size distribution (PSD) of crushed rocks used for concrete casting were created. Table 2 shows the percentage design of coarse aggregate sizes.

Table 2
The percentage of coarse aggregate used.

Size of Coarse Aggregate (mm)	Percentage used for Concrete Casting (%)
5	10
6.3	30
10	20
12.5	15
14	25

3.2 Samples Preparation

For the batch cast in the first section, potable water is utilized in the concrete. In the second step, a 0.5M lime water solution was made by combining 185.23 g of hydrated lime with 5 L of tap water in a container. The lime water was saturated when it was discovered that there was an excess of hydrated lime at the bottom of the jar. Only the top layer of the solution was employed in concrete casting in this experiment, and the settling excess residue was not utilized.

The initial portion of the sample preparation focused on adjusting the fly ash replacement percentage to see how it affected compressive strength at various stages of concrete age. In the experimental, four batches of concrete were produced and consist of OPC concrete with 0% fly ash replacement and HVFA concrete with 40% (HVFA40), 50% (HVFA50) and 60% (HVFA60) fly ash replacement. The OPC concrete was utilized as a control group for comparative purposes. Before the compressive strength test, the cast samples were allowed to cure for 7 days, 28 days, and 56 days.

The influence of saturated lime water on the 7th and 28th day compressive strength of HVFA concrete was the subject of the second portion of the study. Another three batches of HVFA concrete were cast, with 40%, 50%, and 60% fly ash substitution, respectively. The design mix for these three batches of concrete casting was the same as the first, with the exception that saturated lime water was utilized instead of standard potable water for concrete casting. Before the compressive strength test, the cast samples were cured for 7 and 28 days, respectively.

3.3 Design Mix

IS 456:2000 [23] and IS 10262:2009 [24] were used to create the original design mix. During the trial mix, it was discovered that casting HVFA concrete without the use of a superplasticizer with a water to binder ratio of 0.3 is not possible. As a result, the water/binder ratio was raised to 0.5. Table 3 shows the final design combination that was chosen.

Table 3
Design Mix.

	OPC	HVFA 40	HVFA 50	HVFA 60
Percentage of Fly Ash (%)	0	40	50	60
Cement (kg/m ³)	400	240	200	160
Fly Ash (kg/m ³)	0	160	200	240
Water/0.5 M Lime Water (kg/m ³)	200	200	200	200
Fine Aggregate (kg/m ³)	798	798	798	798
Coarse Aggregate (kg/m ³)	1211	1211	1211	1211
Water-Binder Ratio	0.5	0.5	0.5	0.5

3.4 Workability and Compressive Test

Steel cube molds were used to cast 100 x 100 x 100 mm HVFA concrete cube specimens. To make de-molding concrete specimens easier, a coating of oil was added to the inside surface of the steel mold prior to casting. To determine the workability of the mixture, the mixing procedure was completed, and a slump test was performed in accordance with BS EN 12350-2:2019 [25]. The concrete mixture was then poured in three equal layers into the prepared steel molds and compressed with a poker vibrator to remove any voids in the concrete mixture. To minimize moisture loss, the concrete mix was coated with a plastic covering and left within the mold for 24 hours to cure. The concrete was demolded and cured in a water curing tank for 24 hours before the compressive strength tests were performed on the 7th, 28th, and 56th days, respectively. The compressive strength test was performed in line with the BS 12390-3:2019 [26].

3.5 Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS/EDX)

Scanning electron microscopy (SEM) and energy dispersive x-ray/spectroscopy (EDX/EDS) were performed in accordance with ASTM C1723-16 [27] and ASTM E1508-12 [28] standards, respectively. To study the composition, surface structure, and size of the samples, a Hitachi TM4000Plus Tabletop Microscope with a Quantax75TM Series Energy Dispersive X-Ray Spectrometer (Hitachi Ltd., Tokyo, Japan) was utilized. The samples were seen at a 1000x magnification on a few random surface regions of the samples. The elemental composition percentages of the samples are scanned and analyzed by automated software. It was done many times for each sample at various stages, with the most representative findings chosen and recorded.

3.6 Fourier Transform Infrared Spectroscopy (FTIR)

The NWC and CSC samples were FTIR analysed using a Fourier-transform infrared spectroscopy (IRAffinity-1, Shimadzu Corporation, Kyoto, Japan). For qualitative and quantitative examination, Fourier-transform infrared spectroscopy was performed according to ASTM E168-16 [29] and ASTM E1252-98 [30] standards. Each sample had its spectra scanned in the wavenumber range of 4000 cm^{-1} to 400 cm^{-1} . The infrared spectrum transmittance and absorption of the samples were used to create a unique chemical fingerprint spectrum using Fourier-transform infrared spectroscopy. For each sample, the test was performed many times, and the most representative findings were chosen.

4.0 Results And Discussions

4.1 Workability Analysis

The workability of each concrete mix may be compared since the water to binder ratio was set at 0.5 for all the concrete mixes. In comparison to the NWC, the HVFA concrete had a greater workability. Table 4 shows a substantial increase in the workability of HVFA60 concrete when treated with NWC. The spherical form of the fly ash contributed to the increase in workability of HVFA concrete. Fly ash's spherical form decreases friction between the fly ash and other aggregates in the slurry, making it more workable [14, 31].

Table 4
The slump of the concrete mix

<i>Concrete Mix</i>	Slump(mm)	
	No lime water	With lime water
OPC	10	-
HVFA 40	20	10
HVFA 50	20	20
HVFA 60	40	40

4.2 Compressive Strength

At the 7th, 28th, and 56th days, the average compressive strength of NWC and HVFA concrete with 40%, 50%, and 60% fly ash replacements is shown in Fig. 1. At all ages, HVFA40, HVFA50, and HVFA60 concrete samples exhibited lower compressive strength than OPC concrete. Both NWC and HVFA concrete's compressive strength improves as the concrete ages. All HVFA concrete samples had low early age strength compared to NWC at the 7th day, which can be related to the lack of OPC in HVFA concrete, which leads in low early strength development. The compressive strength of HVFA40 and HVFA50 exceeded the average required 28th day structural concrete strength of 30 MPa on the 28th day. The compressive strength of HVFA40 concrete (46.84 MPa) was extremely similar to and equivalent to the NWC concrete at the 56th day (49.28 MPa). However, in 56 days, HVFA50 and HVFA60 concrete exhibited

compressive strengths of 36.88 MPa and 31.72 MPa, respectively, which were lower than the NWC. This may be owing to the delayed pozzolanic reaction that occurs when fly ash is used. Because HVFA50 and HVFA60 include a larger amount of fly ash in their concrete, the pozzolanic reaction takes longer to complete and generate compressive strength. Within the range of 40–60%, no optimal fly ash replacement percentage was discovered. From the findings, it can be inferred that the greater the fly ash replacement percentage, the slower the HVFA concrete's compressive strength growth [14, 15]. However, the ability of the HVFA concrete to surpass the compressive strength of NWC after 56 days is determined by the total binder material (cement + fly ash) and water content utilized in casting the HVFA concrete, not by the proportion of Fly Ash replacement.

The average compressive strength of HVFA concrete with and without saturated lime water at 7th and 28th days, respectively, is shown in Figs. 2 and 3. On the 7th day, it was discovered that HVFA40 and HVFA50 concrete samples cast with saturated lime water had a little decrease in average compressive strength, but HVFA60 concrete samples cast without lime water had a slight rise in average compressive strength. The highest variance in average compressive strength was just 2.94 MPa, indicating that the variation in average compressive strength was quite modest (HVFA50). As a result, the saturated lime water had a less impact on compressive strength growth after 7 days. The OPC contributes the majority of the HVFA concrete's early age compressive strength (at the 7th day), while the pozzolanic reaction of HVFA concrete at this age is extremely modest [5].

However, by 28 days, the influence of saturated lime water on the average compressive strength of HVFA concrete was obvious. Saturated lime water was shown to be efficient in improving the 28th day compressive strength of HVFA50 concrete samples, resulting in a compressive strength of 37.08 MPa, a 23.48% increase above the sample HVFA50 Concrete cast without lime water. This result suggests that an alternative source of calcium hydroxide (lime water) for the fly ash to react, other than the calcium hydroxide released during the cement hydration process, is possible, as it further activates the unreacted fly ash particles within the HVFA50 concrete, resulting in a faster development of the concrete's compressive strength. The compressive strength of HVFA40 and HVFA60 concrete samples cast with saturated lime water was significantly lower than that of those cast without lime water [19].

When lime was added to the fly-ash concrete mixture, the compressive strength of the concrete decreased [19]. This is because the calcium hydroxide (lime water) concentration in the HVFA40 concrete sample exceeded the optimal calcium hydroxide concentration. Excessive hydroxide ions can cause calcium hydroxide to precipitate, preventing the formation of calcium silicate hydrate (C-S-H) gel and lowering compressive strength [32]. The lower compressive strength obtained after adding lime water to HVFA60 concrete was clearly due to a combination of the retardation effect on the early age cement hydration process, which had high alkalinity and insufficient calcium hydroxide within the prepared saturated lime water for activating the fly ash [19].

4.3 Morphological Analysis

SEM images of fly ash and HVFA with lime water are shown in Fig. 4 (a), (b), (c), and (d). Figures 4 (a) and (b) show that the bulk of the fly ash structure is spherical, which is owing to the ball milling and sieving process used in the fine fly ash manufacturing. Figures 4 (a) and (b) show that fly ash particle sizes range from 1 to 100 meters, with the majority of them consisting of solid spheres with varying chemical compositions and surface roughness [33, 34]. Furthermore, the cooling rate and combustion temperature have an impact on the shape of fly ash particles [33]. In Fig. 4 (a) and (b), there were several hollow structures cenospheres (expended mineral materials including alumina and silica), pores/void on the sphere, and irregular shaped fly ash [35]. This might be the result of a faulty carbon burn or a chemical interaction between various components. Figures 4 (c) and (d) indicate that lime water improved the bonding of concrete mixtures, particularly the bonding of gravel. However, as seen in Fig. 4 (d), part of the fly ash is still barely maintaining its typical spherical shape [36]. This was due to a non-chemical interaction between two components that had no influence on the spherical fly ash's structure. On the other hand, it should be noted that not all spherical fly ash particles have a rough pores surface, and a minority of them have a smooth surface, which prevents appropriate mixture bonding.

On Fig. 4 (c), there are several similar phases, and (d). The surface particles were dissolved by the pozzolanic reaction, indicating precipitation, whereas the fly ash particles were activated by $\text{Ca}(\text{OH})_2$ with hydrates replaced by the fly ash particles. The fly ash's hydration pozzolan effect increased the interaction between fly ash, $\text{Ca}(\text{OH})_2$, and other hydration products, in addition to lime water. The packing effect was increased by the smooth passive spherical surfaces of unreacted fly ash particles filler, which resulted in more nucleus precipitation, which binds the fly ash and cement for hydration compounds [37].

4.4 Energy Dispersive X-Ray (EDS/EDX) Analysis

The EDS/EDX element contents for fly ash particles and HVFA concrete with lime water are shown in Tables 5 and 6, respectively. Figures 5 and 6 depict the range of the correlation with the data in Tables 5 and 6. Table 5 indicated elements traces of oxygen (O), carbon (C), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), potassium (K), magnesium (Mg), and titanium (Ti). Table 6 shows the elements traces of oxygen (O), calcium (Ca), silicon (Si), carbon (C), aluminum (Al), iron (Fe), potassium (K), sodium (Na), and magnesium (Mg). The largest mass percentage was oxygen, followed by carbon, silicon, and aluminum, as shown in Table 5. The other elements, on the other hand, have a low mass proportion. Table 6 both showed a similar pattern. This indicates that there is possibility formation of SiO_2 , CaCO_3 , Al_2O_3 , Fe_2O_3 , TiO_2 , K_2O , CaO , MgO , and Na_2O .

Fly ash (Class F) has a greater Si and Al concentration, as well as a more alumino-silicate amorphous structure. This amorphous $\text{Ca}(\text{OH})_2$ interacts with cement hydration processes to form calcium-aluminate-hydrates (Ca-Al-H) and calcium-silicate-hydrates (Ca-Si-H) [37]. The addition of lime water hastened the reaction, which improved and increased it. Low Ca fly ash is classified as Class F, whereas high Ca fly ash includes less non-glass, high amorphous, and other types of low crystalline phases that are not present in high Ca fly ash [37]. Alumino-silicate (Al-Si) glasses make up the low Ca fly ash. Mullite, hematite, quartz, and magnetite are all present in large amounts. These passive crystalline phases are

required for the formation of cementitious hydrates, which are supported by lime water or an alkali such as $\text{Ca}(\text{OH})_2$. Finally, Class F fly ashes have a low alkali (Na_2O) content, which means they are unreactive with concrete alkali and have a higher pH pore solution, which means they do not speed up glass dissolving. It also demonstrates that a chemical reaction took place during the mixing of paste and hydraulic reactivity, resulting in the formation of calcium carbonate, CaCO_3 [38, 39]. CaCO_3 increases early strength because of the accelerator effect and high rate of hydration, which causes the concrete to harden faster [38, 39]. When concrete with CaCO_3 is developed, it has a lower strength than concrete without CaCO_3 , although it is still within the required strength range [38, 39].

Table 5
EDS/EDS element composition for fly ash.

Element	Atomic No.	Mass Normal (%)	Atom (%)	Absolute Error (%) (1 sigma)	Relative Error (%) (1 sigma)
O	8	41.70	43.35	6.35	12.07
C	6	29.48	40.82	5.03	13.52
Si	14	12.59	7.45	0.69	4.35
Al	13	9.43	5.82	0.58	4.89
Fe	26	3.68	1.09	0.18	3.83
Ca	20	1.20	0.49	0.08	5.16
K	19	0.86	0.37	0.07	5.95
Mg	12	0.73	0.50	0.08	8.79
Ti	22	0.35	0.12	0.05	10.40
Total		100	100		

Table 6
EDS/EDS element composition for HVFA concrete with lime water

Element	Atomic No.	Mass Normal (%)	Atom (%)	Absolute Error (%) (1 sigma)	Relative Error (%) (1 sigma)
O	8	64.50	63.09	7.82	12.12
Ca	20	22.70	8.85	0.71	3.12
Si	14	17.00	9.47	0.74	4.34
C	6	11.33	14.75	1.88	16.61
Al	13	3.53	2.05	0.20	5.56
Fe	26	1.89	0.53	0.10	5.24
K	19	1.73	0.69	0.09	4.96
Na	11	0.56	0.38	0.07	12.50
Mg	12	0.42	0.27	0.05	12.92
Total		100	100		

4.4 Infrared Spectral Analysis

The FTIR images for fly ash and HVFA concrete with lime water are shown in Fig. 7 (a) and (b). The loss of $\text{Ca}(\text{OH})_2$ is indicated by a wide band intensity of $4000 - 3500 \text{ cm}^{-1}$. At a band intensity of $3500 - 3000 \text{ cm}^{-1}$, the $(-\text{OH})$ stretching and $(\text{H}-\text{O}-\text{H})$ vibrations bending is seen, while it is designated for water molecules that are absorbed and entrapped in porous structures. The wide band indicated for Si-O-Si bond in quartz ranges from 1600 to 1000 cm^{-1} [37, 40, 41]. CaCO_3 loss is measured at $1000 - 800 \text{ cm}^{-1}$. The stretching of symmetric Si-O-Si and Al-O-Si links indicated at $800 - 500 \text{ cm}^{-1}$ demonstrates the amorphous semi-crystalline alumino-silicate [37, 40, 41]. Finally, the bend O-Si-O and Si-O-Si bonds have designations of less than 500 cm^{-1} band [37, 40, 41]. As a result, the peak number of Class F fly ash and HVFA concrete with lime water are nearly identical. Because of the combination reactions, the addition of lime water to HVFA concrete enhanced structural growth of $-\text{Si}-\text{O}-\text{Al}$ and $-\text{Si}-\text{O}-\text{Si}-$, $\text{Ca}-\text{Si}-\text{H}$, and $\text{Ca}-\text{Al}-\text{H}$ bonds. These results are consistent with the chemical composition as determined by EDS/EDX.

5.0 Conclusions

The workability of HVFA concrete improves as the percentage of Fly Ash substitution increases. As the fly ash compensates for the concrete workability, the need of water reducing agents in real concrete casting is reduced. The compressive strength of HVFA concrete decreases as the fly ash content increases. The compressive strength of HVFA concrete with 40% and 50% fly ash substitution might exceed the average required 28th day compressive strength of 30 MPa. This means that HVFA concrete can be utilized in

ordinary concrete projects with up to 50% fly ash substitution. At the 56th day, HVFA concrete with 40% fly ash substitution is equivalent to NWC, with just a little lower compressive strength. At 7 days, saturated lime water had no effect on the compressive strength of HVFA concrete. The use of saturated lime water to improve the 28th day compressive strength of HVFA concrete with 50% fly ash substitution was discovered to be beneficial. With 40% and 60% fly ash substitution, however, it slows the development of the 28th day compressive strength of HVFA concrete.

Declarations

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Figures

Figure 1

The average compressive strength of OPC and HVFA concrete versus concrete age.

Figure 2

The average compressive strength of HVFA concrete with and without saturated lime water at 7 days.

Figure 3

The average compressive strength of HVFA concrete with and without saturated lime water at 28 days

Figure 4

SEM images of (a), (b), fly ash, and (c), (d) HVFA with lime water.

Figure 5

EDS/EDX spectrum graph for fly ash.

Figure 6

EDS spectrum graph for HVFA concrete with lime water.

Figure 7

FTIR images for (a) fly ash, and (b) HVFA concrete with lime water.