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EFFECT OF ADDITION OF CaO ON COMPRESSIVE STRENGTH OF HIGH-VOLUME FLY ASH CONCRETE

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Abstract — When released into the environment as solid waste, the by-product of coal called fly ash (FA) produced by coal-based electric power plants is detrimental. A further 8% to 10% of the worldwide anthropogenic emissions are produced by cement manufacturers. These issues may be resolved with high-volume fly ash (HVFA) concrete. HVFA concrete technology refers to employing fly ash instead of cement in the concrete mix to reduce the manufacturing of cement. But when the amount of fly ash in the concrete mix increases, the concrete's compressive strength gradually decreases. The objective of this research is to determine the mechanical properties such as the compressive strength of HVFA concrete and compare it to the strength of the control concrete by adding Calcium Oxide (CaO) as an activator. Besides this, this research has another objective to reduce the use of cement in construction by replacing it with fly ash and making an environmentally friendly form of emission of CO_2 while producing cement for the cement industry. In this research, different percentages of FA such as 20, 40, 50, 60, 70, and 80 percent are adopted replacing cement in concrete mixes with and without CaO. For this, cylindrical molds with dimensions of 100 mm × 200 mm were used for preparing concrete specimens. For each percentage of HVFA concrete mixtures, 3 (three) molds were cast without the activator and the same with the activator (2% of the binding material). A total of 117 concrete specimens were cast for the compressive strength test. These molds were cured using the water-curing technique. For determining mechanical properties, the compressive strength tests after 7, 28 and 56 days were conducted. Comparisons were made between the compressive strengths of HVFA concrete with and without the activator. These outcomes were contrasted with the compressive strength of the molds of conventional concrete. The early results for the compressive strength of HVFA concrete are extremely poor. The HVFA concrete's 28-day compressive strength test results demonstrate a much higher compressive strength than the 7-day strength. However, the HVFA concret's 56-day compressive strength test results were more satisfactory. According to this research, long-term water curing effectively boosts the compressive strength of HVFA concrete. Additionally, the use of CaO as an activator in HVFA concrete results in a minimum of 2 MPa higher compressive strength compared to HVFA concrete without the use of an activator. This result was therefore satisfactory for concrete with the activator content for up to 60% HVFA.

Keywords: High volume fly ash concrete, activator, water curing, compressive strength

1.0 INTRODUCTION

It is well known that concrete is strong in compression and has a highly brittle property. In modern civilization, concrete is the most popular construction material due to its numerous advantages. But concrete is weak in ductility and toughness. Currently, blending cement with fly ash, silica fume, slag, or a natural pozzolan and using fly ash in concrete or in roller-compacted concrete (RCC) for pavement and dam applications are widespread. The use of fly ash in concrete is not only economical but also modifies the properties of concrete in both the fresh and hardened state with improvements in workability, strength, and drying shrinkage [1]. In addition, the storage and disposal problem of fly ash, which is an industrial by-product, is also solved by using fly ash in concrete [2].

With the addition of fibers and allowing little variation in compressive strength from plain concrete, these disadvantages can be overcome. It is also known that deformed rebar is used for reinforcing the concrete because deformed rebar gives interlocking properties and gives a good bonding with concrete [3, 4]. In this study, different percentages of fly ashes are used with concrete to study the mechanical properties (compressive strength) of concrete. Fly ash has been used because of its fresh, toughened, and durable qualities. Often in different applications as a substitute for Portland cement. Highly plasticized Concrete made with fly ash at percentages of 20, 30, 40, 50, and 60% by volume (HVFA) was the focus of a lab research [5, 6]. It has been developed to meet the requirements for concrete's strength and workability for pavement construction. discovered that fly ash can be added in amounts of 50–60%. Fly ash from classes C and F were substituted 20–50% of the cement in the metered fly [7, 8] concrete combinations with ash. High volume Class F fly ash blends performed better than those with a low pitch. More effectively than Class C fly ash, Class F fly ash in concrete reduced chloride penetration ash. High volume fly ash mixtures outperformed customary paving materials when it comes to mechanical and durability qualities. Some researchers refer to the finding that using pozzolanic components such as fly ash and metakaolin at a higher strength at 56 days improves the workability of the substitute for OPC lower w/c ratio concrete. When fly ash content went up, it was found that the compressive and tensile strengths decreased [9, 10]. The fly ash used in this project has pozzolanic properties that these trials are successful, and it can be utilized to produce fly ash with high strength and volume. High percentages of up to 50% can be achieved when employing fly ash as an additional material. utilized at lower w/b ratios without losing strength. Moreover, the inclusion of fly ash as a micro filler makes the concrete more impermeable [11, 12]. Fly ash and chemical activators have been investigated in relation to this for over 50 years. Despite this, they are rarely used in Bangladesh's construction industry [13–15].

Meanwhile, the use of FA can reduce the cost of cement production, improve the workability of concrete, reduce the hydration heat, and benefit the drying shrinkage. The advised replacement ratio (weight percentage) of FA used in cement changed initially from 10 to 20% gradually to 25 to35%, and then ultimately to more than 50%. Due to the significant changes of concrete properties by incorporating FA, a definition of high-volume fly ash cement (HVFAC) was specially used for concretes when 50% or more cement was replaced by FA [16]. However, the negative impacts of FA on the early-age mechanical properties and long-term durability properties of HVFAC were severer with the increasing amount of FA. Besides, several studies also proved that the low reactivity of FA and the mechanical properties of HVFAC could be enhanced by mixing various materials such as nano-$CaCO_3$, hydrated lime, set accelerator, silica fume, and metakaolin [17].

One promising method is lime-based activations which use calcium oxide (CaO) or calcium hydroxide ($Ca(OH)_2$) powder as activators. This has merits especially in terms of material cost and workability in concrete [18].

Even though numerous studies have examined the robustness and mechanical properties of Fly ash, cement, and river sand are used to create large volume fly ash concrete. HVFA concrete is used in pavement construction, especially in the application phase. Strength of high-grade Ordinary Portland cement (OPC) is higher than that of OPC including fly ash. Fly ash is a pozzolanic material, thus as it ages, cement activates it. Specific terminology is required for fly ash. Early intervention with therapies including mechanical, chemical, and alkaline activation to similar characteristics to OPC. The concrete's compressive strength after CaO activation and then, an attempt is made to use river sand as the fine aggregate and crushed stone as the coarse aggregate.

In this research, concrete containing power plant-based high volume fly ash i.e., 20%, 40%, 50%, 60%, 70%, and 80% replacement of cement by fly ash will be investigated. Various concrete mixtures with constant water-cementitious material ratio (w/c) will be prepared with the inclusion of high volumes of fly ash as different percentages of cement replacement and CaO as an activator to assess the influence of ash on the mechanical properties of concrete. The overall outcome of this research will facilitate the understanding of the most suitable material combinations to develop an environmental-friendly by HVFA concrete by analyzing the test properties which will be beneficial for the future researchers and practical engineers.

2.0 MATERIALS AND METHODS

2.1 Materials

In this research, the sand was collected from Panchagarh district, and crushed stone was collected from the construction site at Hajee Mohammad Danesh Science & Technology University (HSTU) campus, Dinajpur-5200, Bangladesh.

Lime was used as an activator of high-volume fly ash concrete in this research work. Powdered lime was used for this purpose and collected from Dhaka, Bangladesh.

Binding material is an essential material for concrete. For this research purposes, cement was used as a binding material. Portland cement (PREMIER cement) was used for this purpose. Cement was collected from Dinajpur. For this research, fly ash was used as a partial replacement of cement. Fly ash was collected from Barapukuria coal based powerplant, Parbatipur, Dinajpur, Bangladesh. The materials are used in this research is as shown in Figure 1.

(a) Sand (b) Crushed Stone (c) Lime

(d) Fly Ash (e) Cement

Figure 1 Materials used in this research

2.2 Determination of Material Properties

2.2.1 Sieve analysis of sand and crushed stone

Fineness modulus of sand was determined following the standard procedure recommended by ASTM international in ASTM C136 [19]. For sieve analysis of stone, ASTM C136 was also used.

2.2.2 Specific gravity and water absorption of aggregates

ASTM C127 [20] and ASTM C128 [21] were followed for determining specific gravity and water absorption of stone and sand respectively.

2.2.3 Unit weight of aggregates

Unit weight of stone and sand were determined following ASTM C29 [22] standard.

2.3 Concrete mix preparation

Mix design was prepared according to the standard procedure recommended by ACI international in ACI 211.1-91. After the design, the exact amount of sand, crushed stone, binding material, water were obtained. For this research purpose cement was replaced partially by fly ash. Three major types of concrete mix were prepared: concrete mix without replacement of cement, concrete mix with partial replacement of cement with fly ash and concrete mix with partial replacement of cement with fly ash (using activator). The concrete mix design was prepared to obtain compressive strength of 35 MPa and target slump was 25mm-100mm. The preparation of concrete mixes were shown in Figure 2.

Figure 2 Preparation of concrete mix

2.4 Workability test

After the end of each concrete mix, workability was determined according to ASTM C143/C143M-12.

2.5 Casting of concrete specimen

After mixing and workability test, the concrete specimen was immediately casted, and compaction was done according to ASTM C31/C31-19. Cement was replaced with 20%, 40%, 50%, 60%, 70%, and 80% fly ash in cement concrete mixes with and without CaO (Activator). For casting of concrete specimen, cylindrical molds were used. Cylindrical molds with dimensions of 200 mm × 100 mm were used for preparing concrete specimens. For each percentage of HVFA concrete, three molds were cast without the activator and three molds were prepared with activator (2% of the binding material) for each test. Total 117 specimens were casted for this study. Among them, 9 molds were casted with standard conventional concrete and 108 molds were casted for HVFA concrete.

2.6 Curing of concrete specimen

Curing of concrete specimen was done according to ASTM C31[23] . Completion of 24 hours of casting of concrete, the concrete specimens were removed from molds. For curing of concrete specimen, a water storage tank was used. The concrete specimen was left in the water storage tank for 7-days, 28-days and 56-days. Water curing of the specimens were shown in Figure 3.

Figure 3 Water curing of specimens

2.7 Compressive strength test

The specimen of concrete was tested for compressive strength after the completion of curing of 7-days, 28-days and 56-days. Test was conducted following ASTM C39/C3M-18 standard [24]. The compressive strength test set up was shown in Figure 4.

Figure 4 Compressive strength test setup for the specimens

3.0 RESULTS AND DISCUSSION

3.1 Fineness Modulus of Sand

Fineness modulus of sand was obtained following the standard ASTM C136. The fineness modulus of sand was found to be 2.64. The sieve analysis of fine aggregate was shown in Table 1 and gradation curve was shown in Figure 5.

Table 1 Sieve analysis of fine aggregates

Sieve No.	Weight Retained	Cumulative Weight Retained	Cumulative %retained	% Finer
No. 4	10.2	10.2	1.02	98.98
No. 8	19.2	29.4	2.94	97.06
No. 16	159.4	188.8	18.88	81.12
No. 30	360	548.8	54.88	45.12
No. 50	289.7	838.5	83.85	16.15
No. 100	143.8	982.3	98.23	1.77
Pan	17.7	1000	100	0

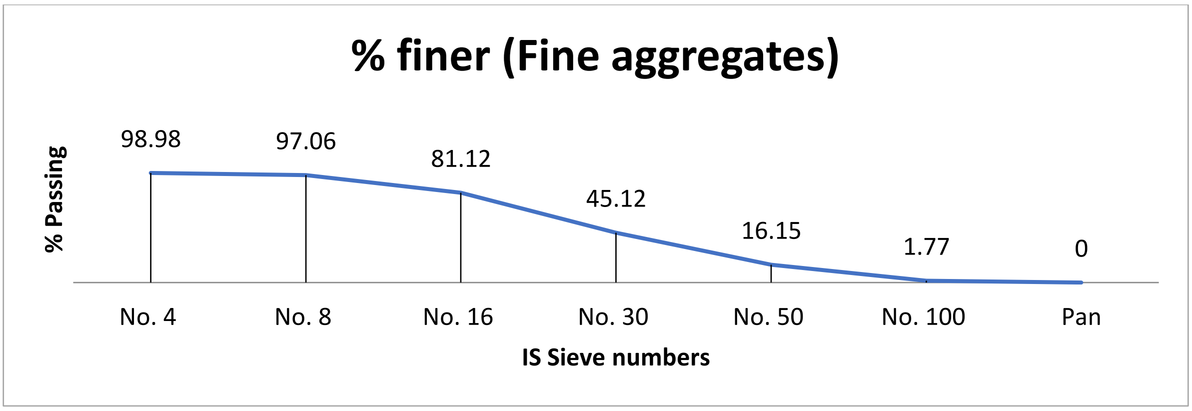


Figure 5 Sieve analysis of sand

3.2 Sieve analysis of Crushed Stone

Sieve analysis of coarse aggregate was performed following the standard ASTM C136. The sieve analysis of fine aggregate was shown in Table 2 and gradation curve was shown in Figure 6.

Table 2 Sieve analysis of coarse aggregates

Sieve	Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative % retained	% Finer
25 mm	43	43	0.86	99.14
19 mm	1391.7	1434.7	28.69	71.31
12.5 mm	2289.7	3724.4	74.48	25.52
9.5 mm	1000	4724.4	94.49	5.51
4.75 mm	268	4992.4	99.84	0.16
2.36 mm	5.2	4997.6	99.95	0.05
1.18 mm	1.9	4999.5	99.99	0.01
0.60 mm	0.3	4999.8	99.99	0.01

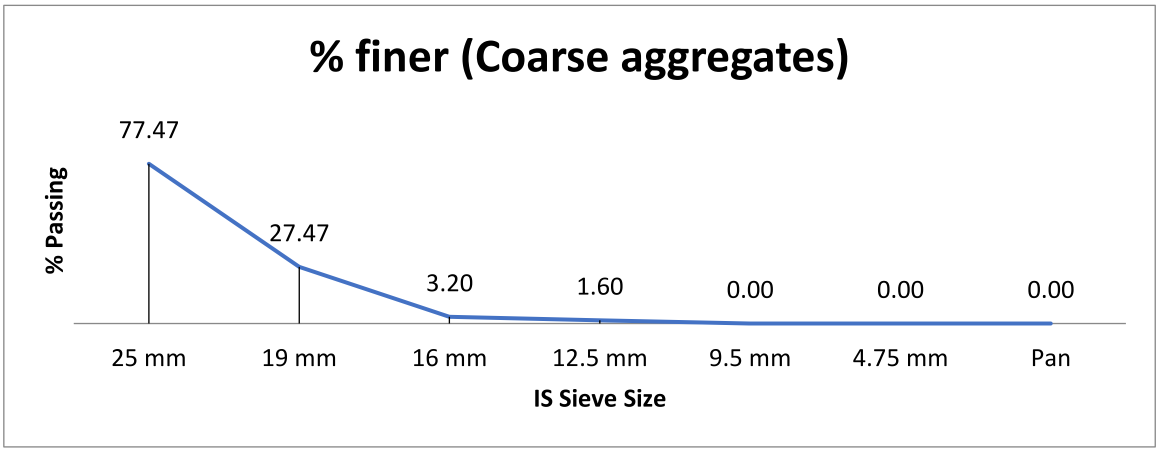


Figure 6 Sieve analysis of coarse aggregates

3.3 Specific Gravity of Sand

According to ASTM C128-15, the specific gravity of sand used in this research was 2.64.

3.4 Unit Weight of Aggregates

Unit weight was tested according to standard ASTM C29. The unit weight of sand and crushed stone was found to be 1555.56 kg/m^3 and 1570.17 kg/m^3 respectively.

3.5 Absorption Capacity of Aggregates

The absorption capacity of sand and crushed stone was obtained by ASTM C128-15 and ASTM C127-15 respectively. The water absorption capacity of sand and crushed stone was found to be 2.8% and 0.43% respectively.

3.6 Specific Gravity of Crushed Stone

In this study, the specific gravity of crushed stone was found to be 2.68 according to ASTM C127-15. The properties of various materials used in this research were shown in Table 3.

Table 3 Various properties of materials used in this research

Name of the Properties	Sand	Crushed stone chips
Fineness modulus	2.64	5.98
Specific Gravity	2.64	2.68
Unit Weight (Kg/m^3)	1555.56	1570.17
Water absorption capacity (%)	2.8	0.43

3.7 Compressive Strength Test

Among all, compressive strength is the most important property of concrete. Concrete has higher compressive strength and lower tensile strength. In this study, 20%, 40%, 50%, 60%, 70% and 80% cement is replaced with fly ash for producing HVFA concrete. Also, along with this fly ash content 2% CaO is used as an activator to enhance the strength of the HVFA concrete. The mold was cured in 7 days, 28 days, and 56 days in water.

3.7.1 Compressive Strength Test for 7 days

After 7 days curing process, the compressive strength of conventional concrete was found 38.61 MPa and high-volume fly ash concrete had given lower compressive strength. The compressive strength of HVFA concrete gradually decreased with increasing the percentage of fly ash in replacement of cement. But HVFA concrete with 2% CaO had given better compressive strength compared to HVFA concrete without activator (CaO). The variation of compressive strength for 7 days test with and without CaO were shown in Table 4 and Figure 7.

Table 4 Compressive strength of 7 days test

7 Days Test Results		
Percentages	**Without CaO**	**With CaO**
100% Cement	38.61	-
20 % Fly Ash	33.78	34.2
40% Fly Ash	22.21	22.42
50% Fly Ash	14.6	14.83
60% Fly Ash	9.75	9.98
70% Fly Ash	4.9	5.11
80% Fly Ash	2.74	3

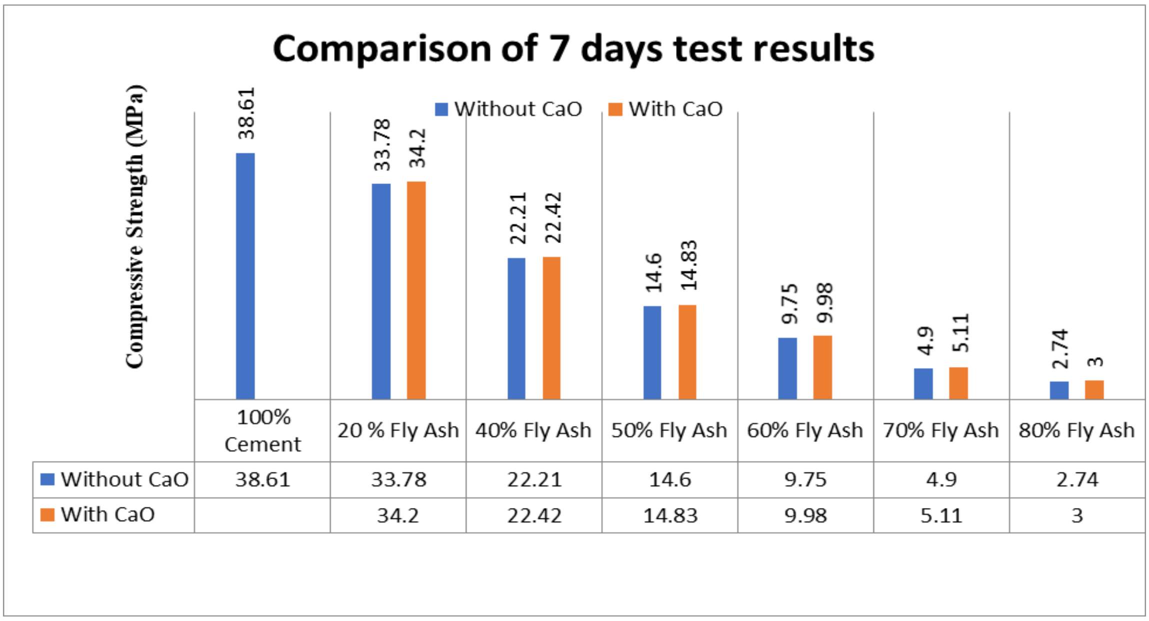


Figure 7 Comparison of 7 days compressive strength of conventional concrete and HVFA concrete without and with activator

3.7.2 Compressive Strength Test for 28 days

After 28 days curing process, the strength of conventional concrete was same i.e 38.61 MPa but this time the compressive strength of HVFA concrete (20%, 40%, 50%, 60%, 70% and 80%) without adding activator gained more strength than the previous 7 days test. Similarly, HVFA concrete (20%, 40%, 50%, 60%, 70% and 80%) with activator gained more strength than the previous 7 days test. The variation of compressive strength for 7 days test with and without CaO were shown in Table 5 and Figure 8.

Table 5 Compressive strength of 28 days test

28 Days Test Results		
Percentages	**Without CaO**	**With CaO**
100% Cement	38.61	
20 % Fly Ash	35.56	38.5
40% Fly Ash	26.31	27.95
50% Fly Ash	17.16	22.8
60% Fly Ash	15.89	16.76
70% Fly Ash	10.14	10.81
80% Fly Ash	3.18	4.76

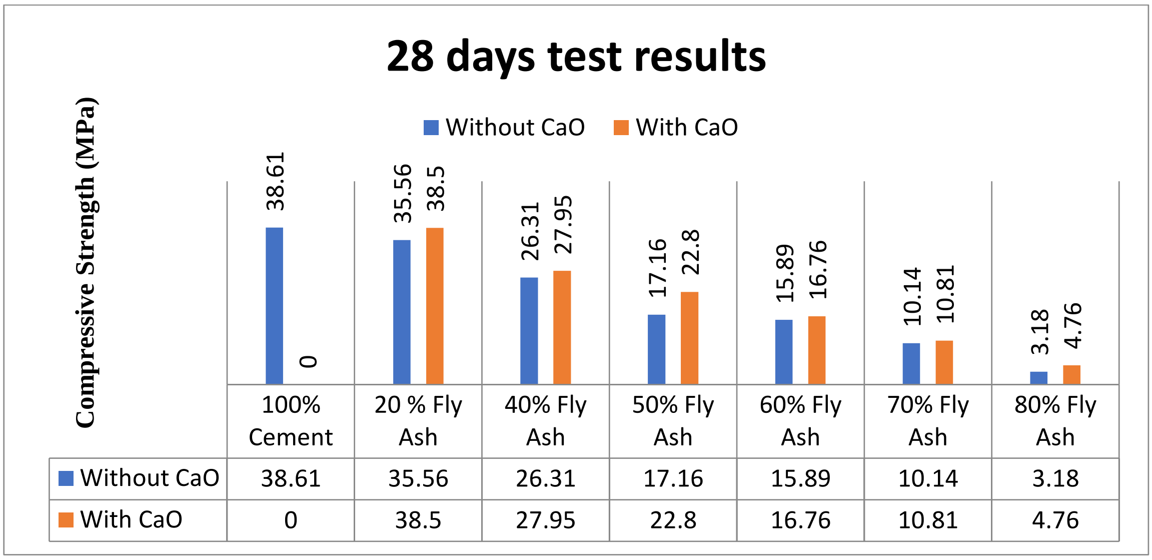


Figure 8 Comparison of 28 days compressive strength of conventional concrete and HVFA concrete without and with activator

3.7.3 Compressive Strength Test for 56 days

After 56 days of curing process, the strength of conventional concrete was slightly increased. It was 38.63 MPa and this time the compressive strength of HVFA concrete (20%, 40%, 50%, 60%, 70% and 80%) without adding activator gained more strength than the previous 7 days and 28 days test. Similarly, HVFA concrete (20%, 40%, 50%, 60%, 70% and 80%) with activator gained more strength than the previous 7 days and 28 days test. The variation of compressive strength for 7 days test with and without CaO were shown in Table 6 and Figure 9.

Table 6 Compressive strength of 56 days test

56 Days Test Results		
Percentages	**Without CaO**	**With CaO**
100% Cement	38.63	0
20 % Fly Ash	40.25	42.78
40% Fly Ash	31.12	35.46
50% Fly Ash	28.33	30.03
60% Fly Ash	19.96	21.77
70% Fly Ash	14.43	16.35
80% Fly Ash	5.2	7.06

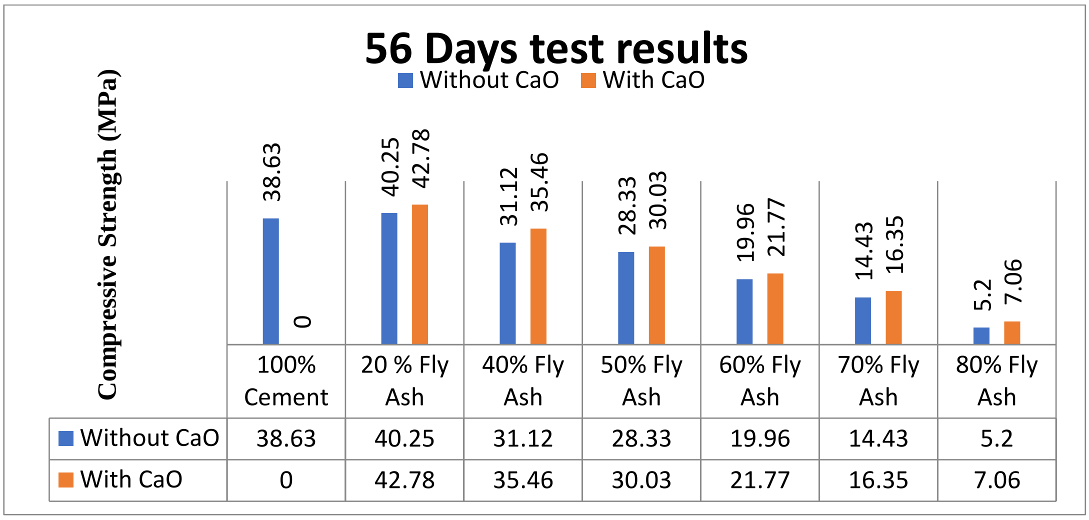


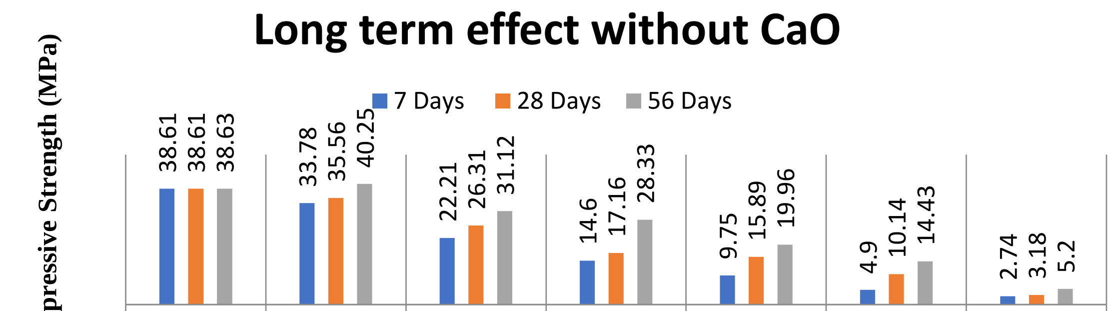
Figure 9 Comparison of 56 days compressive strength of conventional concrete and HVFA concrete without and with activator

3.7.4 Long Term Effect of HVFA concrete

From the test results, it was found that HVFA concrete gains more strength in long term aspects. The comparison of 7, 28 and 56-days compressive strength without activator were shown in Table 7 and Figure 10 and with activator were shown in Table 8 and Figure 11.

Table 7 Comparison of the long term effects without CaO

The long-term effects without CaO			
Percentages	**7 Days**	**28 Days**	**56 Days**
100% Cement	38.61	38.61	38.63
20 % Fly Ash	33.78	35.56	40.25
40% Fly Ash	22.21	26.31	31.12
50% Fly Ash	14.6	17.16	28.33
60% Fly Ash	9.75	15.89	19.96
70% Fly Ash	4.9	10.14	14.43
80% Fly Ash	2.74	3.18	5.2

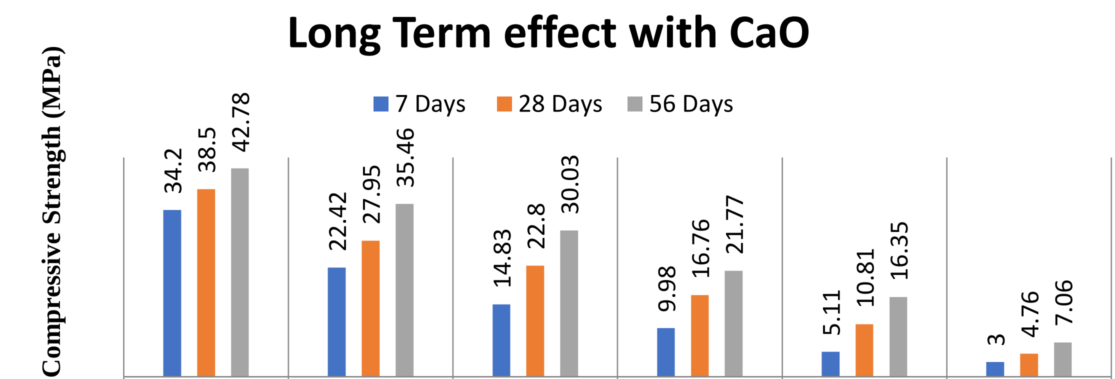


	100% Cement	20 % Fly Ash	40% Fly Ash	50% Fly Ash	60% Fly Ash	70% Fly Ash	80% Fly Ash
7 Days	38.61	33.78	22.21	14.6	9.75	4.9	2.74
28 Days	38.61	35.56	26.31	17.16	15.89	10.14	3.18
56 Days	38.63	40.25	31.12	28.33	19.96	14.43	5.2

Figure 10 Comparison of 7 days, 28 days and 56 days compressive strength of conventional concrete to HVFA concrete without using activator

Table 8 Comparison of the long term effects with CaO

The long-term effects with CaO			
Percentages	**7 Days**	**28 Days**	**56 Days**
20 % Fly Ash	34.2	38.5	42.78
40% Fly Ash	22.42	27.95	35.46
50% Fly Ash	14.83	22.8	30.03
60% Fly Ash	9.98	16.76	21.77
70% Fly Ash	5.11	10.81	16.35
80% Fly Ash	3	4.76	7.06



	20 % Fly Ash	40% Fly Ash	50% Fly Ash	60% Fly Ash	70% Fly Ash	80% Fly Ash
7 Days	34.2	22.42	14.83	9.98	5.11	3
28 Days	38.5	27.95	22.8	16.76	10.81	4.76
56 Days	42.78	35.46	30.03	21.77	16.35	7.06

Figure 11 Comparison of 7 days, 28 days and 56 days compressive strength of conventional concrete to HVFA concrete with activator

4.0 CONCLUSION

In this research work, different percentages of FA such as 20%, 40%, 50%, 60%, 70%, and 80% were used to determine the mechanical properties such as compressive strength of concrete. It can be concluded that

- In our investigation, the 7-day test result shows that conventional concrete shows the maximum strength, which is 38.6MPa. On the other hand, the compressive strength by replacing cement with fly ash at 20% was 33.78 MPa without an activator and increased slightly after using CaO. The other specimen made by replacing 40%, 50%, 60%, 70%, and 80% of cement shows gradually decreased compressive strength.
- In 28 days, the test result shows a constant result of 100% cement, but the compressive strength of fly ash concrete has increased after using CaO, 50% fly ash concrete shows a remarkable change in compressive strength.
- Long-term test result such as the 56-day test result shows that 20% fly ash concrete gives more compressive strength than conventional cement concrete with 40%, 50%, 60%, 70% and 80% replacement of cement by fly ash. Concrete gives satisfactory strength after using CaO.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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