EXPERIMENTAL STUDY ON HIGH STRENGTH CONCRETE USING FLY ASH

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A thesis submitted to the Department of Civil Engineering in partial fulfillment for the degree of Bachelor of Science in Civil Engineering

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Section: 27A
Semester: 12th (Fall-2025)

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Dedicated

To

“Our Beloved Parents”

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ABSTRACT

This study investigates the compressive strength performance of high-strength concrete incorporating fly ash as a partial replacement of cement, with an emphasis on achieving sustainability without compromising strength characteristics. Although fly ash offers significant environmental and durability benefits, its use at higher replacement levels is often associated with reduced early-age strength. To overcome this limitation, the present research focuses on reducing the water–binder ratio and utilizing a high-range water-reducing admixture. Concrete mixes were prepared with fly ash replacement levels of 0%, 20%, and 40% by weight of binder. The control mix was designed with a water–binder ratio of 0.283, while the fly ash blended mixes were produced with reduced water–binder ratios of 0.220 and 0.205, respectively. A Sika high-range water-reducing admixture (HRWR) was incorporated in all mixes to ensure adequate workability at low water–binder ratios. Cylindrical concrete specimens were cast and cured under standard conditions, and compressive strength tests were conducted at 28 days. The results indicate that a reduction in the water–binder ratio significantly enhances the compressive strength performance of fly ash blended concrete. Despite the higher fly ash content, the mixes with lower water–binder ratios exhibited improved strength behavior due to reduced porosity, enhanced particle packing, and a denser cementitious matrix. The findings demonstrate that the combined use of reduced water–binder ratio and superplasticizer effectively compensates for the early-age strength reduction typically associated with fly ash. This approach provides a viable and sustainable method for producing high-strength concrete while reducing cement consumption.

TABLE OF CONTENTS

Contents

INTRODUCTION

1.1 General

Concrete is one of the most widely used construction materials in the world due to its versatility, durability, and cost effectiveness. Conventional concrete generally provides compressive strength in the range of 20–40 MPa, which is sufficient for ordinary structures. However, with the rapid development of modern infrastructure such as high-rise buildings, long-span bridges, prestressed concrete structures, and heavy industrial facilities, the demand for concrete with higher strength and better durability has significantly increased. This demand has led to the development and application of High Strength Concrete (HSC).

High Strength Concrete is generally defined as concrete having a compressive strength greater than 40 MPa. The production of HSC requires careful selection of materials, low water–binder ratio, and the use of chemical admixtures to maintain adequate workability. In recent years, the incorporation of supplementary cementitious materials such as fly ash has gained considerable attention due to both performance enhancement and environmental benefits.

1.2 High Strength Concrete

High Strength Concrete differs from conventional concrete primarily in its mix design and material composition. The strength of concrete depends on factors such as the quality of cement, aggregate properties, water–binder ratio, curing conditions, and the use of admixtures. In HSC, a lower water–binder ratio is essential to achieve higher strength, which often results in reduced workability. To overcome this limitation, superplasticizers are commonly used to improve workability without increasing water content. HSC offers several advantages over normal strength concrete, including higher load-carrying capacity, reduced member size, improved durability, and better resistance to environmental effects. These properties make HSC suitable for use in structures where high performance is required.

1.3 Use of Fly Ash in Concrete

Fly ash is a by-product obtained from coal-fired thermal power plants and is widely used as a supplementary cementitious material in concrete. It contains reactive silica and alumina, which react with calcium hydroxide produced during cement hydration to form additional calcium silicate hydrate (C-S-H) gel. This pozzolanic reaction contributes to improved strength and durability of concrete at later ages.

The use of fly ash in concrete offers several benefits, including reduced heat of hydration, improved workability, enhanced long-term strength, and reduced permeability. Moreover, the utilization of fly ash helps in reducing cement consumption, thereby lowering carbon dioxide emissions associated with cement production and promoting sustainable construction practices.

1.4 Need for the Present Study

Superplasticizers are high-range water-reducing admixtures that significantly improve the workability of concrete without increasing the water content. In the production of high strength concrete, superplasticizers play a crucial role by enabling the use of a low water–binder ratio while maintaining sufficient flow and compaction characteristics.

The combined use of fly ash and superplasticizer allows for the production of dense and high-performance concrete. Superplasticizers enhance particle dispersion, reduce water demand, and improve the overall quality of concrete, making them essential components in HSC mix design.

Although fly ash has been widely used in conventional concrete, its application in high strength concrete requires further experimental investigation, particularly at the undergraduate level. The behavior of fly ash concrete at different curing ages, especially early-age and later-age strength development, needs to be clearly understood.

This study aims to experimentally investigate the effect of fly ash as partial replacement of cement in high strength concrete using superplasticizer. The compressive strength performance of concrete at 7 days and 28 days curing periods is evaluated and compared with a control mix to determine the optimum use of fly ash in high strength concrete.

1.6 Objectives of the Study

The main objectives of this study are:

- To produce high strength concrete using fly ash as partial replacement of cement
- To determine the compressive strength of concrete at 7 and 28 days
- To study the effect of fly ash on early-age and later-age strength development
- To evaluate the role of superplasticizer in achieving low water–binder ratio concrete
- To compare the performance of fly ash concrete with conventional concrete

1.7 Scope of the Study

The scope of this study is limited to laboratory-based experimental investigation. The research focuses primarily on the compressive strength characteristics of high strength concrete incorporating fly ash and superplasticizer. Durability aspects and long-term performance are beyond the scope of the present study.

CHAPTER 2
LITERATURE REVIEW

2.1 General

The construction industry in Bangladesh has experienced rapid growth over the last few decades due to increasing urbanization, population growth, and infrastructural development. The construction of high-rise buildings, bridges, flyovers, industrial plants, and other critical infrastructures requires concrete with higher strength, improved durability, and better long-term performance. Conventional concrete often fails to meet these demands, particularly under aggressive environmental conditions such as high humidity, salinity, and temperature variations prevalent in Bangladesh.

At the same time, the excessive use of Portland cement has raised concerns regarding environmental sustainability, as cement production is a major source of carbon dioxide emissions. To address these issues, the use of supplementary cementitious materials (SCMs) such as fly ash has gained significant attention. Fly ash not only reduces cement consumption but also improves the mechanical and durability properties of concrete. In Bangladesh, fly ash is mainly produced from coal-based thermal power plants and is increasingly being considered as a viable construction material.

Several researchers have investigated the use of fly ash in concrete under Bangladeshi conditions. These studies mainly focus on strength development, workability, durability, and economic benefits. This chapter reviews the available literature related to high strength concrete, fly ash utilization, the role of chemical admixtures, and strength development at different curing ages, with particular emphasis on Bangladesh-based research.

2.2 High Strength Concrete in the Context of Bangladesh

High strength concrete (HSC) is generally defined as concrete having a compressive strength greater than 40 MPa. The development of high strength concrete primarily depends on low water–binder ratio, proper mix proportioning, quality materials, and the use of chemical admixtures. In Bangladesh, the production of high strength concrete using locally available materials has been explored by several researchers.

Hossain et al. (2010) conducted experimental studies on high strength concrete using locally sourced aggregates and cement. Their results indicated that compressive strength exceeding 40 MPa could be achieved by maintaining a low water–cement ratio and using superplasticizers. They emphasized that the quality of aggregates and proper grading play a significant role in achieving higher strength.

Rahman and Islam (2012) investigated the performance of high strength concrete under Bangladeshi climatic conditions. They reported that high ambient temperature and humidity significantly influence hydration and strength development. Their study highlighted that proper curing is essential to prevent early-age cracking and strength loss, especially in high strength concrete applications.

2.2 Fly Ash as a Supplementary Cementitious Material in Bangladesh

Fly ash is a finely divided pozzolanic material produced as a by-product of coal combustion in thermal power plants. When used in concrete, fly ash reacts with calcium hydroxide released during cement hydration to form additional calcium silicate hydrate (C–S–H) gel, which contributes to strength and durability improvement.

Islam and Islam (2012) examined the potential use of Bangladeshi fly ash in concrete and concluded that locally available fly ash possesses suitable chemical and physical characteristics for use as a supplementary cementitious material. Their study showed that fly ash reduces water demand and improves workability, making it particularly suitable for high strength concrete.

Ahmed et al. (2014) studied the compressive strength behavior of concrete incorporating different percentages of fly ash. They observed that replacing cement with 20% to 30% fly ash resulted in reduced early-age strength but significant strength gain at later ages. The study concluded that fly ash-based concrete is more suitable for structures where long-term performance is more critical than early strength.

2.3 Effect of Fly Ash on High Strength Concrete

The incorporation of fly ash in high strength concrete has been found to enhance both fresh and hardened properties. Khan and Al-Amin (2015) investigated the effects of fly ash on the workability and strength of high strength concrete. Their experimental results indicated that fly ash improves workability due to its spherical particle shape and reduces the heat of hydration, which is beneficial for mass concrete construction.

Hasan et al. (2017) focused on the durability aspects of fly ash concrete under aggressive environmental conditions common in Bangladesh, such as chloride and sulfate exposure. They reported that fly ash significantly reduces permeability and chloride penetration, thereby enhancing the service life of reinforced concrete structures, especially in coastal and marine regions.

2.4 Role of Superplasticizer in Fly Ash Based Concrete

Superplasticizers are high-range water-reducing admixtures that are essential for producing high strength concrete with low water–binder ratios. In Bangladesh, the availability of different commercial superplasticizers has encouraged extensive research on their effectiveness.

Sarker et al. (2013) evaluated the performance of several locally available superplasticizers in fly ash-based concrete. Their study revealed that the combined use of fly ash and superplasticizer improves particle dispersion, enhances workability, and results in a more homogeneous and dense concrete matrix. This combination allows for significant reduction in water content without compromising workability.

The study concluded that the use of superplasticizers is indispensable for producing high strength concrete incorporating fly ash, particularly when low water–binder ratios are required.

2.5 Strength Development at Different Curing Ages

The strength development of fly ash concrete is strongly influenced by curing age. Due to the slower pozzolanic reaction of fly ash, early-age strength is generally lower compared to conventional concrete. However, long-term strength gain is significantly higher.

Rahman et al. (2016) studied the compressive strength development of fly ash concrete at different curing ages. They reported that at 7 days, fly ash concrete exhibits lower strength, but at 28 days and beyond, the strength increases rapidly and often exceeds that of control concrete.
Islam et al. (2018) further reported that prolonged curing enhances the pozzolanic activity of fly ash, resulting in improved microstructure, higher compressive strength, and enhanced durability. These findings suggest that fly ash-based high strength concrete is particularly suitable for long-term structural applications in Bangladesh.

2.6 Research Gap

From the reviewed literature, it is evident that fly ash has significant potential as a supplementary cementitious material for producing high strength and durable concrete in Bangladesh. Most studies confirm that fly ash improves workability, long-term strength, and durability while reducing environmental impact.

However, the optimum percentage of fly ash replacement varies depending on material characteristics, mix proportions, and curing conditions. Additionally, most available studies have been conducted using advanced laboratory facilities and controlled experimental conditions.

There is a noticeable lack of experimental research at the undergraduate level focusing on the comparative compressive strength performance of fly ash-based high strength concrete at early (7 days) and later (28 days) curing ages using locally available materials. Therefore, the present study aims to experimentally investigate the effect of fly ash as a partial replacement of cement on the compressive strength of high strength concrete under Bangladeshi conditions.

CHAPTER 3
METHODOLOGY

3.1 Materials

In this study, cement, fine aggregate, coarse aggregate and fresh water are used to reduce desire concrete mix. Sand was used as fine aggregate and stone chips were used as coarse aggregate and potable water was used in the investigations for both mixing and curing.

Cement

Cement, in general, adhesive substances of all kinds, but, in a narrower sense, the binding materials used in building and civil engineering construction. Cements of this kind are finely ground powders that, when mixed with water, set to a hard mass. Setting and hardening result from hydration, which is a chemical combination of the cement compounds with water that yields submicroscopic crystals or a gel-like material with a high surface area. Because of their hydrating properties, constructional cements, which will even set and harden under water, are often called hydraulic cements. The most important of these is Portland-cement.

Specifications of Cement

Name	: Scan Cement (Ordinary Portland Cement)
Specific gravity of cement	: 3.15
Setting times of cement	: i) initial setting time 30 minutes ii) Final setting time 10 Hours
Weight	: 50 Kg.
BDS EN 197-1	: 2010, CEM I/ 52.5N, ASTM C-150
Clinker	: 95-100%
Limestone	: 5-15%
Gypsum	: 0-5%

Fine aggregate

Aggregate significantly influences rheological and mechanical properties on both mortars and concrete. Fine aggregate being a main component in concrete production has a significant part to play in influencing concrete strength. Sand is commonly used as the standard material for a fine aggregate. In this same type of sand was used as the fine aggregate for both with admixture and without admixture in this study as shown in below figure. The sand was washed with water and air dried before being used to obtain Saturated Surface (SSD) condition.

Figure 1: Sand as Fine Aggregate

Coarse aggregate

Aggregate materials help to make concrete mixes more compact. They also decrease thconsumption of cement and water and contribute to the mechanical strength of the concrete, making them an indispensable ingredient in the construction and maintenance of rigid structures aggregate materials help to make concrete mixes more compact. They also decrease the consumption of cement and water and contribute to the mechanical strength of the concrete, making them an indispensable ingredient in the construction and maintenance of rigid structures. Coarse aggregates are particulates that are greater than 4.75mm. The usual range employed is between 9.5mm and 37.5mm in diameter. In this type of stone chips (Black stone) had been used as a coarse aggregate as shown in the Figure.

Figure 2: Black stone as a coarse aggregate

Water

Water is critical in the making of concrete. Adding water to the mix sets of a chemical reaction when it comes into contact with the cement. The water used in the mixing of concrete is usually of a potable standard. Using non-drinking water or water of unknown purity risks the quality and workability of the concrete.

3.2 Seive Analysis

For particle size distribution for both coarse and fine aggregate sieve analysis method ware uses according ASTM Cl36.

Apparatus
For sieve analysis, following apparatuses ware used-
a) Balance;
b) Sieves;
c) Oven and
d) Containers.
e) Brash.

3.3 Test Procedure

- Clean the sieves of sieve shaker using cleaning brush if any particles are struck in the openings.
- Record the weight of each sieve and receiving pan.
- Dry the specimen in oven for 3-4 minutes to get the dried specimen (ignore, if the specimen is already dried).
- Weigh the specimen and record its weight.
- Arrange the sieves in order as the smaller openings sieve to the last and larger openings sieve to the top. (Simply, arrange them to the ascending order of sieve numbers – No.4 sieve on top and no.200 sieve at bottom)- Sieve numbers and the particle sizes are provided below in a chart for further understanding.
- Keep the weight recorded specimen on the top sieve and then keep the complete sieve stack on the sieve shaker (Don't forget to keep the lid and receiving pan).
- Allow the shaker to work 10-5 minutes – use the clock here.
- Remove the sieve stack from the shaker and record the weight of each sieve and receiving pan separately.

Figure 3: Sieve Analysis

3.3 Concrete Mix Properties

For this Research mixture proportion of concrete were determine in accordance with following condition:
Without any replacement of cement Mixing Ratio 1:0.5:2
20% Fly Ash replacement of cement Mixing Ratio 1:1:2.5:0.25

40% Fly Ash replacement of cement Mixing Ratio 1:1:3.25:0.66

Three concrete mixes were prepared with fly ash replacement levels of 0%, 20%, and 40%, designated as M0, M1, and M2, respectively. The water–binder ratio of the control mix (M0) was maintained at 0.283. For the fly ash blended mixes, the water–binder ratio was reduced to 0.220 for M1 and 0.205 for M2 to achieve high-strength performance. The superplasticizer dosage was kept constant for all mixes to ensure consistent workability. Cylindrical specimens were cast and cured under standard conditions, and compressive strength tests were conducted at 28 days.

3.4 Concrete Moulding Procedure

- For compressive and tensile strength test, steel cylindrical mold was used. Height and diameter of the mold were 200mm and 100mm respectively.
- Molds were cleaned and grease was applied on the inner surface of the mold. Concrete was filled in the mold in 3 layers.
- Each layer was rodded 25 time in an even pattern using a tamping rod. After tamping, the top surface is leveled.
- The molded specimens were kept at normal temperature to dry.

Molding of cylinder concrete specimens are shown in figure.

Figure 5: Concrete mixing and molding

Figure 6: Mold of Cylinder

CURING PROCESS OF CYLINDERS

After 24 hours of casting, the concrete specimens were removed from the mold and allowed for curing. Here, we used one type curing method:

3.5 Immersion Curing Method

Figure 7: Immersion Curing Method

3.6 Compressive Strength Test of Cylinders

We can use the Universal Testing Machine (UTM) for compressive strength tests of RCC cylinders. There are some images of compressive strength test-

Figure 8: Universal Testing Machine (UTM)

CHAPTER 4

RESULT AND ANALYSIS OF LAB TEST

This result can be used to determine the correlation of compressive strength of concrete cylinder and the recommended curing period respectively. The result as the strength increases with the decreases of curing time interval.

4.1 Sieve Analysis of Fine Aggregate

The test sample of the aggregate (F.M) shall weigh, after drying.

Table 4.1: Sieve Analysis of Fine Aggregate

Sieve Number	Sieve Opening (mm)	Materials Retained (gm)	% Materials Retained	Cumulative % retained	Percent finer
4	4.75	0	0		
8	2.36	41	4.1	4.1	95.9
16	1.19	280	28	32.1	67.9
30	0.59	275	27.5	59.6	40.4
50	0.30	304	30.4	90	10
100	0.15	81	8.1	98.1	1.9
Pan		19			
Total				283.9	

Fineness Modulus = 2.839

Figure 9: Sieve Analysis

4.2 Sieve Analysis of Coarse Aggregate

Table 4.2: Sieve Analysis of Coarse Aggregate

Sieve Number	Sieve Opening (mm)	Materials Retained (gm)	% Materials Retained	Cumulative % retained	Percent finer
3/4	19.05	207	20.7	20.7	79.3
3/8	9.5	778	77.8	98.5	1.5
4	4.75	15	1.5	100	0
8	2.36	0	0	100	0
16	1.19	0	0	100	0
30	0.59	0	0	100	0
50	0.30	0	0	100	0
100	0.15	0	0	100	0
Pan					
Total				7192	

Fineness Modulus = 7.192

4.3 Specific Gravity of Fine Aggregate

Table 4.3-1: Data sheet for specific gravity of fine aggregate

Wt. of pycnometer Filled with water to Calibration mark. **B gm**	Oven Dry Wt. in Air **A gm**	Wt. of pycnometer with Specimen and water to Calibration mark. **C gm**	Wt. of S.S.D. sample in Air **S gm**
657	305	850	315

Table 4.3-2: Specific gravity of fine aggregate

Tests	Formula	Calculation	Results
Apparent Specific Gravity	$\frac{A}{B+A-c}$	$\frac{305}{657+305-850}$	2.72
Bulk Specific Gravity (Oven Dry Basis)	$\frac{A}{B+S-C}$	` $\frac{305}{657+315-850}$	2.5
Absorption Capacity, D%	$\frac{S-A}{A}*100$	$\frac{315-305}{305}*100$	3.27
Bulk Specific Gravity (S.S.D. Basis), G	$\frac{S}{B+S-C}$	$\frac{315}{657+315-850}$	2.58

The apparent specific gravity of the local sand as fine aggregate after oven drying was found 2.72. We found the bulk specific gravity for oven dry basic was 2.5. Apparent capacity redaction received 3.27. And bulk SSD received 2.58.

Figure 10: Specific gravity of fine aggregate

4.4 Specific Gravity of Coarse Aggregate

Table 4.4-1: Data sheet for specific gravity of coarse aggregate

Wt. of S.S.D Samle in Air, B (gm)	Wt. of S.S.D Sample in Water, C (gm)	Oven Dry Wt. Of Sample in Air, A (gm)
1650	1050	1605

Table 4.4-2: Data sheet for specific gravity of coarse aggregate

Tests	Formula	Calculation	Results
Apparent Specific Gravity	$\frac{A}{A-C}$	$\frac{1605}{1605-1050}$	2.89
Bulk specific Gravity (S.S.D. Basis)	$\frac{B}{B-C}$	$\frac{1650}{1650-1050}$	2.75
Bulk specific Gravity (Oven dry Basis)	$\frac{A}{B-C}$	$\frac{1605}{1650-1050}$	2.67
Absorption capacity, D%	$\frac{(B-A)*100}{A}$	$\frac{(1650-1605)*100}{1605}$	2.80

Figure 11: specific gravity of coarse aggregate

4.5 Unit weight of Fine Aggregates

Table 4.5: Data sheet for unit weight of fine aggregates

Procedure	Wt. of Bucket (gm)	Wt. of Bucket+Material (gm)	Wt. to Material (gm)	Average Wt. of Material (gm)	Volume Of Bucket V (ft^3)	Unit Weight, M (gm/cft)
Shoveling	4000	7986	3986	3986	0.00278	1434
Rodding	4000	8389	4389	4389	0.00278	1579
Jiggling	4000	8594	4594	4594	0.00278	1652

Average Unit Weight, M =1555

Discussion:
The experimental results demonstrate that the unit weight of fine aggregates is significantly influenced by the method of compaction. The shoveling method resulted in the lowest unit weight (1434 gm/cft), which can be attributed to a higher percentage of voids within the aggregate mass. The rodding method yielded an increased unit weight of 1579 gm/cft due to improved particle arrangement and partial densification. The jiggling method produced the maximum unit weight (1652 gm/cft), reflecting enhanced compaction and reduced void content. The average unit weight of the fine aggregate was determined to be 1555 gm/cft, which may be adopted as a representative value for practical engineering and material characterization purposes.

Figure 12: Unit weight of fine aggregates

4.6 Unit weight of Coarse Aggregates

Table 4.6: Data sheet for unit weight of coarse aggregates

Procedure	Wt. of Bucket (gm)	Wt. of Bucket+Material (gm)	Wt. to Material (gm)	Average Wt. of Material (gm)	Volume Of Bucket V (ft^3)	Unit Weight, M (gm/cft)
Shoveling	4000	7881	3881	3881	0.00278	1396
Rodding	4000	8404	4404	4404	0.00278	1584
Jiggling	4000	8483	4483	4483	0.00278	1612

Average Unit Weight, M =1530

Discussion:
The experimental results reveal that the unit weight of fine aggregates varies notably with the method of compaction employed. The shoveling method produced the lowest unit weight of 1396 gm/cft, which is attributed to minimal compaction and a higher proportion of void spaces within the aggregate mass. In contrast, the rodding method resulted in an increased unit weight of 1584 gm/cft due to improved particle interlocking and partial densification. The highest unit weight, 1612 gm/cft, was obtained using the jiggling method, indicating enhanced particle rearrangement and maximum compaction efficiency. The average unit weight of fine aggregates was calculated as 1530 gm/cft, which may be considered a representative value for material characterization and practical engineering applications.

Figure 13: Unit weight of coarse aggregates

4.7 Cylinder Test Results

Table 4.7-1: 7 Days Cylinder Test Results

Sample %	Dia of Cylinder (mm)	Height of Cylinder (mm)	Weight of Cylinder (kg)	Crushing Value (KN)	Compressive Strength (MPa or N/mm^2)	Average Compressive Strength (MPa)
0%	103	206	4.148	220	26.40	26.41
	101.4	207	4.204	224	27.74	
	101.2	200	3.906	205	25.09	
20%	104	204	4.166	254	29.90	33.60
	101.2	204	4.028	280	34.81	
	102	205	3.950	295	36.10	
40%	101.4	204.4	4.166	310	38.43	36.60
	101.9	205	4.028	298	35.76	
	101.7	205	3.920	285	35.75	

It is observed from the test results that both the wet covering method & spraying water method of curing gave better strength of cylinder for Indian Black Stone at 7 days.

Table 4.7-2: 28 Days Cylinder Test Results

Fly Ash Replacement (%)	Dia of Cylinder (mm)	Height of Cylinder (mm)	Weight of Cylinder (kg)	Crushing Value (KN)	Compressive Strength (MPa or N/mm^2)	Average Compressive Strength (MPa)
0%	101.5	206	4.054	283	34.98	37.68
	101.8	204	3.991	305	37.47	
	101.9	206	4.111	331	40.68	
20%	101.2	206	4.150	403	50.10	48.20
	102.2	205	4.217	388	47.30	
	101.2	204	4.093	380	47.24	
40%	103	206	4.171	451	54.13	52.10
	102.8	207	4.154	426	51.33	
	101.2	208	4.044	409	50.85	

It is observed from the test results that both the wet covering method & spraying water method of curing gave better strength of cylinder for Indian Black Stone at 28 days.

Table 4.7-3: 7 Days Summary of the Cylinder Test Results

Mix ID	Fly Ash Replacement (%)	Water-Binder Ratio (w/b)	Superplasticizer Type	Superplasticizer Dosage (% of binder)	Average Compressive Strength (MPa)
M0	0	0.283	Sika (HRWR)	1.20	26.41
M1	20	0.220	Sika (HRWR)	1.20	33.60
M2	40	0.205	Sika (HRWR)	1.20	36.60

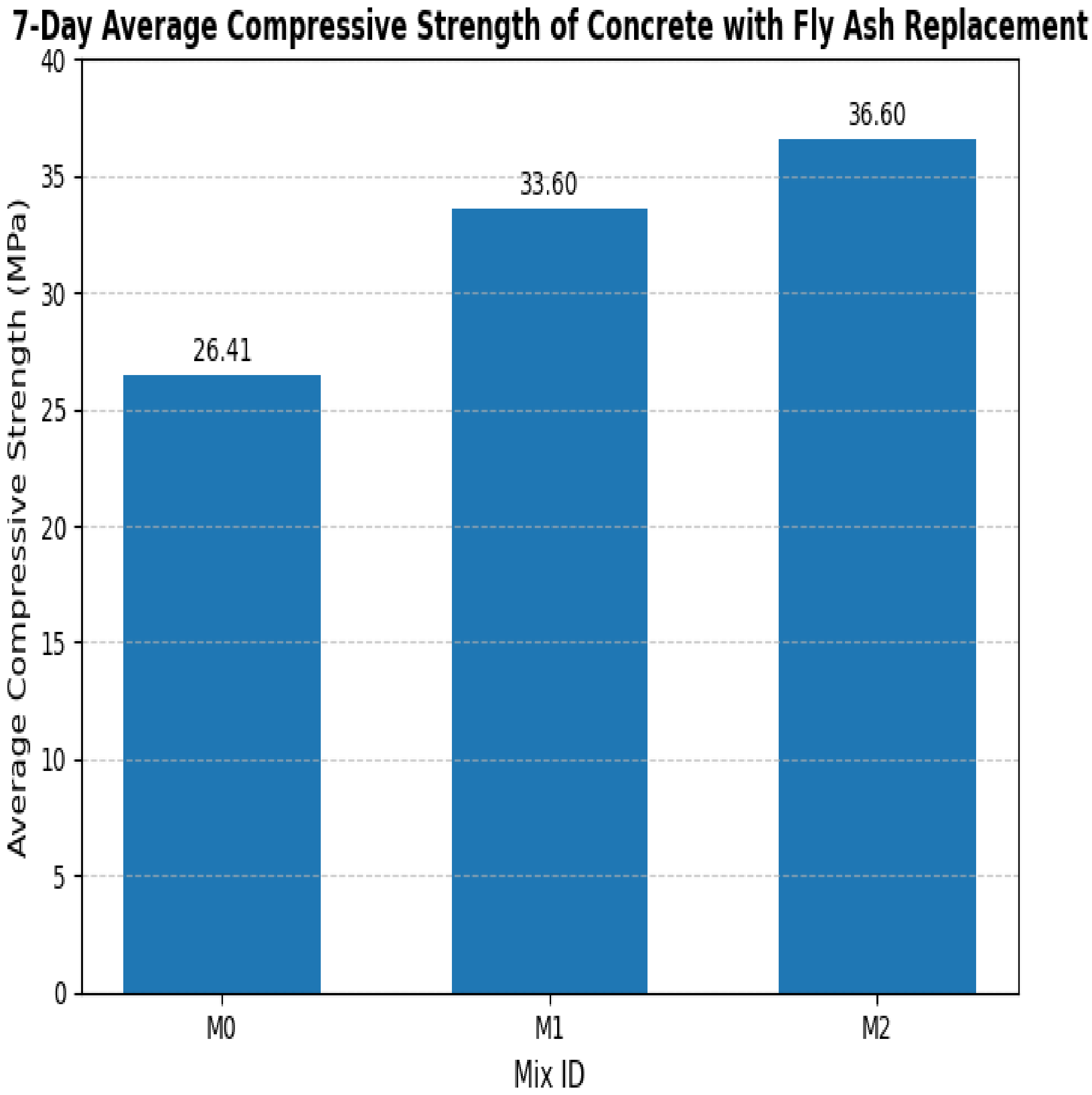

Figure 14: Chart of 7 days test result

Table 4.7-4: 28 Days Summary of the Cylinder Test Results

Mix ID	Fly Ash Replacement (%)	Water-Binder Ratio (w/b)	Superplasticizer Type	Superplasticizer Dosage (% of binder)	Average Compressive Strength (MPa)
M0	0	0.283	Sika (HRWR)	1.20	37.68
M1	20	0.220	Sika (HRWR)	1.20	48.20
M2	40	0.205	Sika (HRWR)	1.20	52.10

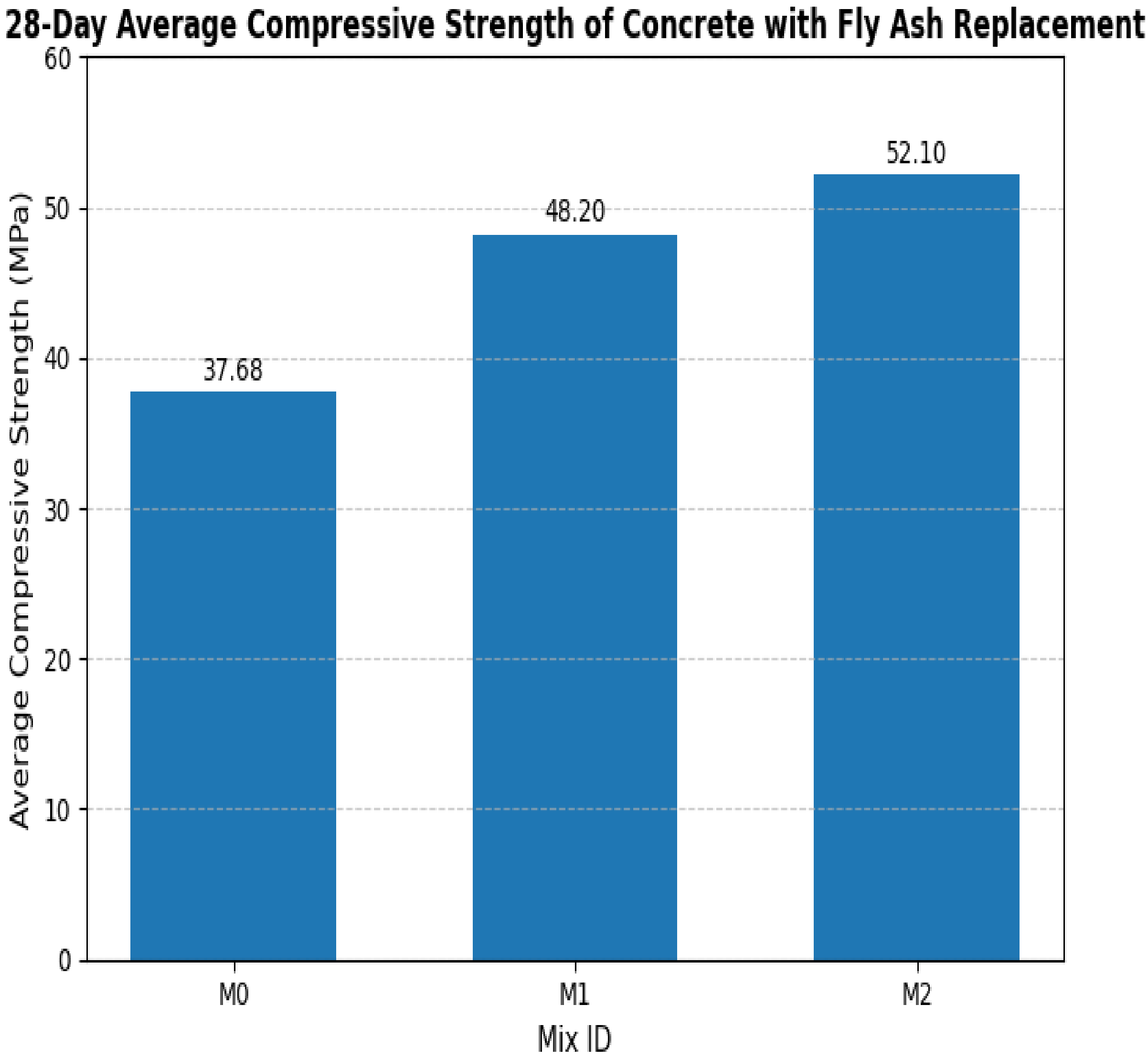

Figure 15: Chart of 28 days test result

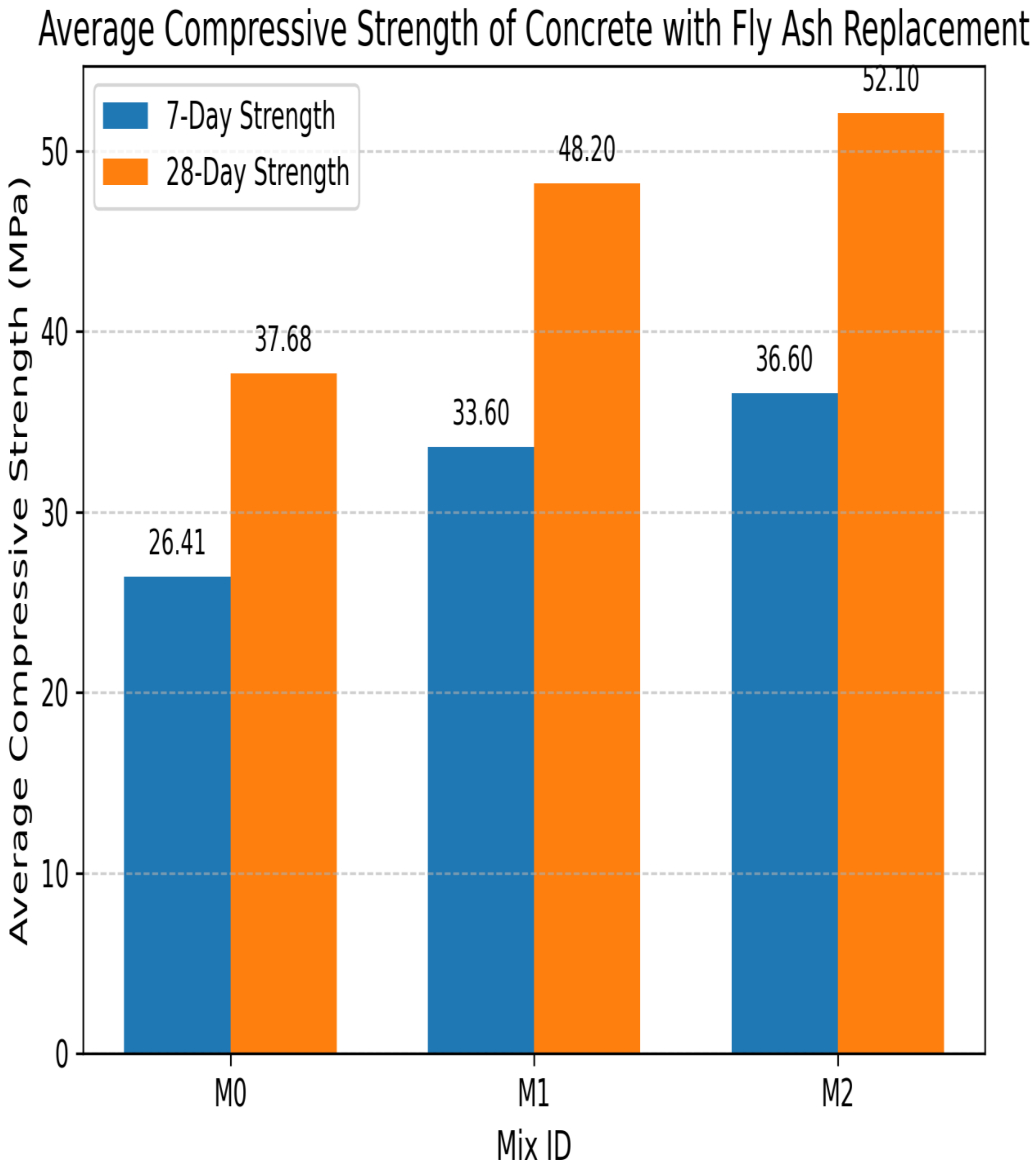

Figure 16: Chart of 7&28 days test result

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 General

This chapter presents the conclusions drawn from the experimental investigation carried out on high-strength concrete incorporating fly ash as a partial replacement of cement. The study focused on improving the compressive strength performance of fly ash blended concrete by reducing the water–binder ratio and using a Sika high-range water-reducing admixture. Based on the experimental results obtained from compressive strength tests on cylindrical specimens at 28 days, the key findings are summarized and appropriate conclusions are presented.

5.2 Conclusions

- The control mix with 0% fly ash replacement achieved an average compressive strength of **37.68 MPa** at 28 days, indicating the baseline strength performance of conventional concrete at a water–binder ratio of 0.283
- The concrete mix containing **20% fly ash replacement (M1)**, with a reduced water–binder ratio of 0.220 and the use of Sika superplasticizer, achieved a significantly higher average compressive strength of **48 MPa**. This demonstrates that partial replacement of cement with fly ash, combined with proper mix design modification, can enhance compressive strength.
- The concrete mix with **40% fly ash replacement (M2)** exhibited the highest average compressive strength of **52 MPa** at 28 days when a lower water–binder ratio of 0.205 and Sika HRWR superplasticizer were used. This indicates that high-volume fly ash concrete can achieve high strength under optimized conditions.
- The results confirm that **reducing the water–binder ratio** plays a critical role in increasing compressive strength, and its effect can effectively offset the reduction in early-age strength typically associated with higher fly ash content.
- The use of **Sika high-range water-reducing admixture (HRWR)** was essential in maintaining adequate workability at low water–binder ratios, contributing to the formation of dense and uniform concrete.
- Contrary to conventional behavior, the study demonstrates that **higher fly ash replacement levels**, when combined with superplasticizer and reduced water–binder ratio, can produce concrete with superior 28-day compressive strength.
- Overall, the findings indicate that **40% fly ash replacement**, along with reduced

water–binder ratio and superplasticizer, is effective for producing **high-strength and sustainable concrete**, while significantly reducing cement consumption.

5.3 Recommendations

Based on the findings of the present study, the following recommendations are made:

- Further studies are recommended to investigate the **long-term compressive strength** of fly ash blended concrete at 56 days, 90 days, and beyond, in order to better understand the later-age strength development due to pozzolanic reactions.
- The effect of **different types and dosages of superplasticizers** may be examined to optimize workability and strength performance at very low water–binder ratios.
- Future research may focus on the combined use of **fly ash with other supplementary cementitious materials**, such as silica fume or ground granulated blast furnace slag (GGBS), to further enhance early-age and long-term strength.
- The **durability properties** of high-volume fly ash concrete, including water absorption, permeability, sulfate resistance, and chloride penetration, should be evaluated to assess long-term performance in aggressive environments.
- Microstructural studies using techniques such as **Scanning Electron Microscopy (SEM)** or **X-ray Diffraction (XRD)** are recommended to better understand the hydration products and pore structure of high-strength fly ash concrete.
- The influence of **curing methods and curing duration** on strength and durability of low water–binder ratio concrete should be investigated to identify the most effective curing practices.
- Future studies may also assess the **economic and environmental benefits**, including cost reduction and carbon footprint analysis, associated with high-volume fly ash replacement in high-strength concrete.

5.4 Scope for Future Work

The present study was limited to compressive strength evaluation at a specific curing age. Further research can be carried out in the following areas:

- Study of strength development at longer curing periods such as 56 days and 90 days. Investigation of durability properties such as water absorption, permeability, and resistance to chemical attack.
- Microstructural analysis using techniques such as SEM and XRD to better understand the pozzolanic reaction of fly ash.
- Use of different types of fly ash and comparison with other supplementary cementitious materials such as silica fume or GGBS.
- Study of combined use of fly ash and other mineral admixtures for enhanced performance.

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