

A COMPARISON OF THE STRENGTH AND COSTS OF HIGH VOLUME AND NORMAL FLY ASH CONCRETE

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ABSTRACT

The construction industry is rapidly expanding to keep pace with industrialization and infrastructure development, with concrete playing an indispensable role. However, the making of Portland cement, the primary binder in concretes, is a mainly contributing to greenhouse gas emanations, exacerbating global warming and climate change. Meanwhile, the disposal of fly ash, a by-product of industry from coal burning in thermal power plants, poses a significant challenge worldwide. High-volume fly ash concretes (HVFAC) emerge as a key to these environmental concerns, promising increased sustainability in construction practices.

Currently, there's a lack of specific guidelines, such as IS codes, for the mixing and production of HVFAC, necessitating thorough investigation. The global production of fly ash stands at around 600 million tons, with India alone generating approximately 110 million tons annually. Despite efforts to utilize fly ash in various applications like fillings, embankments, and construction materials, a substantial portion remains underutilized and disposed of in harmful ways.

Thorough research is necessary to fully utilise fly ash in concrete; this includes a special focus on fly ash from India and locally sourced materials. Three stages of experimental research have been carried out to evaluate the effectiveness of high volume and low volume fly ash concrete (LVFAC and HVFAC). Tests for elastic moduli, split tensile strength, flexural strength, and compressive strength at various ages were included in these investigations.

Results indicate that HVFAC can achieve compressive strengths comparable to traditional concrete mixes at later ages, owing to its pozzolanic properties. Additionally, fracture studies, impact strength assessments, and chemical exposure testing were supported out to estimate resilience. Statistical modeling of parameters influencing the strength characteristics of fly ash mixes further enhances understanding and optimization of concrete production processes.

In conclusion, the adoption of high-volume fly ash concrete holds promises for justifiable structure building practices. Through careful material selection, precise mixing techniques, adequate curing, and optimal superplasticizer dosage, the construction industry can transition towards producing high-performing and environmentally friendly concrete structures.

Key Words: Normal Fly Ash Concrete, , High Volume Fly Ash Concrete, Cost Analysis, Concrete Mix Design, Fly Ash Utilization, Compressive Strength

1. INTRODUCTION

Fly ash, a significant component that is not naturally cementitious, is a byproduct of coal-burning power plants. On the other hand, when it is finely crushed and allowed to get wet, it chemically interacts with calcium hydroxide to produce materials that resemble cement. During this process, calcium ions interact with the alumino-silicates found in fly ash to form calcium silicate hydrates. FA is increasingly being utilized in place of Portland cement in concrete mixtures as a developing trend in contemporary construction techniques.

Three important variables are the main drivers of this tendency. First and foremost, economics is important because FA is usually cheaper than the Portland cement. Thus, the total cost of production goes down as fly ash content in concrete goes up. Secondly, using FA in concrete has a positive ecological impact by preventing this industrial byproduct from building up in landfills. Furthermore, the CO₂ emissions linked to the creation of concrete are reduced by using fly ash instead of Portland cement, which promotes environmental sustainability. Thirdly, when used properly, HVFAC has several noteworthy technical aids, especially in terms of durability.

adding large amounts of FA to concrete mixes has obvious advantages in terms of the economy, ecology, and technology, there is a noticeable lack of knowledge about the properties of this kind of concrete as well as no direction on how to produce and use it. Therefore, in order to maximise its advantages and lessen the ecological impact of FA buildup in landfills, the goal of this inquiry is to inspect efficient methods of by means of both high and low volume FA in concrete.

FLY ASH**OBTAINABILITY OF FA MATERIAL**

At now, the approximate amount of FA produced worldwide is 600 million tonnes. About 230–250 million tonnes of coal are used yearly in India, where coal powers more than 75% of power plants. This contributes in the production of about 110 million tonnes of fly ash annually. This amount is probable to rise to around 170 million tonnes by 2010. Even with this abundance, fills, embankments, building and the production of fly ash blocks and tiles only use thirty percent of the fly ash generated. Thermal plants produce over 2.7 million tonnes of fly ash in Tamil Nadu alone. Regrettably, a big expanse of fly ash produced—especially in India—is handled wet and dumped in ash ponds, endangering the ecosystem. FA is a left-over product from thermal power plants that is not used to its full potential, which is unfortunate given India's large coal reserves. The use of FA in large volume FA concrete has significant potential due to its distinct physico-chemical characteristics. Its existing disposal techniques, however, fall short of fully realising this promise. Investigating novel strategies to optimise the advantageous application of FA is vital, especially in the context of environmentally friendly building methods.

Application of Fly Ash

Currently, fly ash substitution of cement is limited to 35 percent per Indian standard IS 456-2000. But even at this level of usage, a large quantity of fly ash is left behind, which means that precious land must be utilised to dispose of it. In India, the widely held of studies on FA concrete concentrate on using FA instead of cement to the tune of 30% to 40%, especially in high volume FA (HVFA) concrete studies.

Research indicates that after 28 days, the application of large amounts of class F FA in lieu of some of the cement lowers the material's modulus of elasticity, abrasion resistance, strength at flexure, split tensile strength, and strengths at compression. On the other hand, significant progress is seen at 56 and 90 days. However, since fly ash quality varies from one supplier to another, the suggested mix combinations in this research may not work for you.

1. **Reduced Cement Content:** Partially substituting Portland cement with FA in large-scale concrete mixtures. This replacement can range from 20% to 60% or even higher, liable on the specific requirements and performance characteristics anticipated for the concrete.
2. **Improved Workability:** Incorporating fly ash into high-volume concrete mixes can enhance workability and reduce water demand. This allows for easier placement and compaction of the concrete without sacrificing strength or durability.
3. **Decreased Heat of Hydration:** The use of fly ash aids in reducing the heat produced when concrete hydrates. This is especially helpful for mass concrete applications or big concrete pours where preventing thermal cracking requires careful temperature increase management.
4. **Enhanced Durability:** By enhancing resistance to sulphate attack, alkali-silica reaction (ASR), chloride intrusion, and other types of chemical and physical degradation, FA prolongs the long-term durability of high-volume concrete. Concrete constructions benefit from a longer service life and less maintenance as a result.
5. **Environmental Benefits:** Significant reductions in carbon dioxide emissions and energy consumption related to the manufacturing of cement can be accomplished by partially substituting fly ash for cement in high-volume concrete. This lessens the negative ecological effect of building operations and is in line with sustainability aims.
6. **Cost Savings:** Incorporating fly ash into high-volume concrete mixes can result in cost savings by reducing the overall cement content required for construction projects. Additionally, improved workability and durability may lead to lower maintenance costs over the lifespan of the concrete structure.

USES OF SUPERPLASTICIZER

Superplasticizer primarily serves to improve fluidity and workability in concrete mixes. Its addition induces repulsion, leading to deflocculation and subsequent enhancement of mix fluidity. Superplasticizers are admixtures commonly used in high-volume concrete to improve workability, reduce water content, and enhance the performance of the concrete mix. Here are several key uses of superplasticizers in high-volume concrete:

1. **Improved Workability:** Superplasticizers effectively disperse cement particles, reducing the friction between them. This results in increased workability and flowability of the concrete mix, allowing for easier placement and compaction without the need for excessive water content.
2. **Water Reduction:** The reduction of the water-to-cement ratio (w/c ratio) in combinations of concrete while preserving the required functionality is one of the major purposes of superplasticizers. Superplasticizers contribute to the strength and durability of concrete by lowering the quantity of water required for a particular slump and lowering shrinkage and breaking.

3. Enhanced Strength and Durability: These substances enhance the compressive strength, flexural strength, and general resilience of high-volume concrete mixes by permitting a lower water percentage and a greater cementitious material content. This is especially crucial for building projects that call for outstanding performance concrete.

High-Volume Fly Ash Concrete) Requirement:

1. Sustainability: By using more fly ash as a supplemental cementitious material (SCM), HVFAC lessens the environmental effect of producing concrete. This lessens the carbon impact that comes with making cement.
2. Cost Reduction: HVFAC may reduce material prices by substituting a large amount of FA for cement, particularly in areas where fly ash is easily accessible at no cost or at a reduced cost.
3. Improved Workability: By enhancing the flowability and workability of concrete mixtures, fly ash in HVFAC reduces the requirement for excessive water content, facilitating simpler placement and compaction. This is especially advantageous for major building projects.

Low-Volume Fly Ash Concrete) Requirement:

1. Performance criteria: LVFAC could be chosen over HVFAC in particular situations where certain performance criteria must be satisfied. LVFAC gives the concrete mix designer more control over the mix design by allowing the fly ash content to be adjusted to obtain the appropriate durability, workability, and strength characteristics.
2. Availability of Fly Ash: LVFAC could be more sensible in areas where fly ash is scarce or of inconsistent quality. Although fly ash qualities vary, LVFAC permits flexibility in fly ash utilisation, guaranteeing that the concrete mix satisfies performance and quality criteria.
3. Compatibility with Other Admixtures: LVFAC offers more versatility when it comes to using chemical additives, air-entraining agents, and superplasticizers. This makes it possible to create concrete mixes that are specifically suited to the needs and building circumstances of a given project.
4. Regulatory Considerations: Fly ash usage in concrete mixes may be restricted by regulations or standards for certain building projects. In these situations, LVFAC provides a substitute that satisfies legal requirements and partially makes use of fly ash's advantageous qualities.

2. OBJECTIVES

1. Determine if high- and low-volume FA concrete are suitable for practice in civil engineering applications by carrying out extensive strength testing in compliance with Indian requirements and evaluating the findings.
2. Examine the efficient practice of huge quantities of Indian fly ash with the goal of mitigating environmental pollution by replacing cement at levels ranging from 10% to 60% in both LVFAC and HVFAC with locally accessible materials.
3. Evaluate the long-term efficacy of LVFAC and HVFAC via comprehensive durability studies, which include admixture testing.
4. Create mathematical models based on experimental results to establish links between the components of concrete in order to forecast its strength and durability.

3. LITERATURE REVIEW

India will become increasingly dependent on regular Portland cement to encounter the growing needs of the constructional industry if new technologies and procedures aren't put in place to incorporate larger amounts of accompanying cementing material like fly ash into concrete creation, or if blended cements with significant SCM percentages aren't used as much. CO₂ emissions would significantly increase on this track.

HVFAC may reduce the requirement for regular Portland cement while maintaining high-quality concrete appropriate for a variety of applications by properly balancing mixes and using regionally accessible ingredients and chemical admixtures. This strategy greatly reduces environmental impact while placing a high priority on practicality, cost-effectiveness, and performance.

RATIONALE FOR THE CURRENT INVESTIGATION

As evident from the preceding discussion, a significant amount of fly ash remains underutilized, posing substantial environmental risks when disposed of in landfills. This inadequate management of fly ash threatens the integrity of living habitats. However, leveraging the pozzolanic possessions of FA in conjunction with cement presents an opportunity to effectively utilize the profuse fly ash resources in our country.

These finding endeavors to capitalize on this opportunity by developing highly durable, high-strength concrete

formulations at minimal cost. By harnessing the probable of FA in concrete production, the aim is to mitigate ecological threats related to fly ash disposal while simultaneously advancing sustainable construction practices.

STRENGTH CHARACTERISTICS OF FA CONCRETES

In order to achieve various grades of concrete ranging from 30 to 70 MPa, Binu Sukumar et al. (2007) examined the application of high-volume FA in SCC mixtures. The study's goal was to retain necessary rheological qualities including flow ability and segregation resistance. According to the research, SCC presented a faster rate of strength growth than regular concrete of equivalent grades.

The viability of using Turkish fly ashes in the construction of HVFAC was examined by Burak Felekoglu (2006). Concrete mixes were compared to standard concrete in terms of mechanical qualities and material costs by substituting fly ash for cement in different ratios. The research stressed how crucial it is to choose fly ashes with certain chemical and physical characteristics in order to create HVFAC for construction practice that is both economically and technically feasible.

Additional studies, such those conducted by Feldman et al. (1990) and Cheng Cao et al. (2000), beheld at the mechanical characteristics and strength expansion of high-volume fly ash concrete for structural applications and roller-compacted concrete for structural applications, respectively. This research demonstrated how adding fly ash to concrete may rally its motorized qualities and durability while having a less negative environmental effect. All in all, these investigations further our knowledge of the usage of FA in concretes manufacturing, emphasising how it may enhance concrete properties and solve environmental issues at the same time.

CONCRETE FRACTURE

In past decades, there has been a significant prominence on comprehending and mitigating concrete cracking, recognizing its profound implications for structural stability. Engineers have increasingly turned to fracture mechanics to scrutinize concrete fracture patterns, offering a notable advancement in structural analysis. Concrete strength is deeply influenced by inherent imperfections and aggregate composition, factors that can induce size-dependent behavior when integrated into analytical models. Furthermore, the rate of loading plays a pivotal role in material response, a characteristic observed across various materials.

Integrating fracture mechanics into concrete assessment represents a progressive approach to ensuring infrastructure longevity and safety, supplementing traditional structural analysis methods. This interdisciplinary approach delves into the intricacies of concrete cracking and fracture behavior, refining engineers' understanding of structural vulnerabilities. By applying fracture mechanics, engineers can gain invaluable insights into the behavior of concrete structures with pre-existing cracks, aiding in their assessment and reinforcement.

notch depths. Remarkably, the findings revealed a consistent trend in fracture toughness regardless of the variation in test specimen shapes and notch depths. This indicates the robustness and reliability of the observed fracture toughness characteristics in both concrete and fiber-reinforced concrete materials, highlighting the potential applicability of these findings across various structural scenarios.

In his research, Bazant (1983) delved into the Size Effect in Blunt Fracture, aiming to elucidate the behavior of the resilient zone at the breakage front concerning varying specimen sizes. Through his analysis, Bazant demonstrated that despite changes in specimen size remained relatively consistent. This crucial finding suggests that elastic-plastic fracture also exhibits a analogous size upshot phenomenon. By uncovering this relationship, Bazant's work contributes to a deeper understanding of fracture mechanics and the underlying mechanisms governing the behavior of materials under varying conditions of size and loading.

high-volume FA, indicating its viability. These blends showed excellent mechanical qualities and showed resilience to chloride penetration and freeze-thaw cycles despite having less cement in them. This study highlights the possibility of using FA and SF mixes to create high-performance, long-lasting concrete, providing information on environmentally friendly building methods. In recent decades, a multitude of studies have explored the utilization and characteristics of FA in concrete, shedding light on its potential applications and benefits. Rafat Siddique's (2004) research focused on Class F fly ash usage in concrete, revealing its viability as a cement replacement up to 50%, with a continuous improvement in strength attributes due to pozzolanic reaction over time. Aitcin (2003) delved into durability experiments on High-Performance Concrete (HPC), uncovering its robust resistance against various chemical, geometrical, physical, and mechanical factors, rendering it suitable for challenging maritime conditions. Cengiz Duran Atiş (2002) made notable observations regarding fly ash concrete, noting a lower maximum temperature increase with higher replacement levels, particularly relevant in heat development research.

4. METHODOLOGY

It is essential to choose materials carefully and comprehend their interactions in order to generate both LVFAC and HVFAC. The key ingredients in the creation of concrete are fine aggregate, fly ash, cement, coarse aggregate, water, and chemical admixtures. These ingredients work together to give the finished product the desirable qualities, such as strength, durability, ease of handling, and environmental friendliness. There are a number of performance needs that should be considered while creating these concrete mixtures, including

1. Strength: Ensuring the concrete satisfies the necessary standards for compressive strength in order to maintain structural integrity.
2. Durability: Increasing the concrete's resistance to abrasion, chemical assaults, and freeze-thaw cycles to increase its lifespan.
3. Workability: Reaching the required level of uniformity and positioning convenience to speed up building.
4. Shrinkage and cracking: Reducing the possibility of long-term deformation and cracking, which might jeopardise the stability of the structure.

USED INGREDIENTS

The subsequent resources were utilized in this investigation:

1. Regular Portland Cement, Grade 53; BIS compliant; 12269-1987. Table 3.1 provides a thorough breakdown of the cement sample test findings.
2. Class F fly ash with properties listed in Table 3.2 that was procured in a single batch from the Mettur Thermal Power Station to ensure uniformity throughout the experiment.
3. Superplasticizer, DON-SUPAFLOW, a chemical admixture that satisfies ASTM C 494 (1992) and BIS: 9103-1999 requirements, is based on sulphonated naphthalene formaldehyde condensate. Table 3.3 lists the superplasticizer's properties.
4. Crushed blue granite stones from nearby sources that meet graded aggregate requirements and have a nominal size of 20 mm, in accordance with BIS: 383-1970. Details on coarse aggregates, such as their specific gravity of 2.6, are given. According to BIS: 2386-1963, aggregate testing was carried out, and Table 3.4 contains the tabulated findings.
5. Locally obtained river sand with a sp. Gr. of 2.53 that satisfies BIS Grading Zone II requirements: 383-1970.
6. Local drinkable water applied for the curing and mixing of the concrete.

Cement

A powder that has been finely ground and contains calcium silicates, aluminates, and ferrites, cement is an essential part of construction. It hydrates when combined with water to generate a paste that binds particles together to build concrete. Different varieties of cement, such as PPC and OPC, have different qualities for different uses. The paste changes during setting, hardening gradually over time as it goes from a plastic to a solid state. Conditions during the curing process and the composition of the cement can have an impact on strength growth. Ensuring consistency and reliability in cement manufacturing is facilitated by strict quality control, and efforts to reduce environmental effect through sustainable techniques are constantly evolving. In order to satisfy the demands of sustainable development, cement continues to be essential in modern building, spurring innovation toward greener and more efficient manufacturing techniques.

Aggregates

Forming 60% to 80% of the volume of concrete, aggregates are essential components that include both fine and coarse particles. While large aggregates like crushed stone and gravel give the mixture strength and mass, fine aggregates like sand fill in spaces and improve workability. The mechanical, thermal, and acoustic qualities of concrete are influenced by their quality; clean, well-graded aggregates are essential for longevity and functionality. Reducing the environmental impact of building waste through sustainable measures like recycling it for aggregates is becoming more and more significant. Superior and long-lasting concrete constructions require a thorough understanding of and efficient use of aggregates.

Fine Natural Aggregate

Particles smaller than 5 millimeters are known as fine natural aggregate, and they are often obtained from riverbeds. Fine natural aggregate is essential to concrete compositions. Sand is its main component, generated throughout time by the weathering and erosion of rocks. By occupying the spaces left by the coarse aggregates and cement paste, fine natural aggregate makes the mixture more cohesive and improves the workability of concrete. It is appropriate for a variety of tasks, including plastering and finishing work, because of its smooth texture, which enhances the look and

finish of concrete surfaces. Concrete performance is The outcome heavily relies on the standard of the fine natural aggregate used, with workability, strength, and durability being prejudiced by the shape, size, and cleanliness of the constituent part. To guarantee the supply of premium fine natural aggregate for building while reducing environmental effect, sustainable extraction methods and appropriate management of river resources are essential.

Fly Ash

As a result of coal combustion in thermal power plants, fly ash is commonly employed as an extra cementitious component in concrete production. Fly ash, which is made up of tiny particles extracted from flue gas using bag filters or electrostatic precipitators, has pozzolanic qualities. In the presence of water, when it interacts with calcium hydroxide, it generates cementitious compounds akin to those produced during cement hydration. Calcium silicate hydrate (CSH), one of the extra cementitious chemicals produced by this reaction, increases the strength and durability of concrete. Adding fly ash to concrete not only mitigates alkali-silica reaction (ASR) and lowers heat generation during hydration, but it also makes the material more workable, uses less water, and develops long-term strength. These advantages collectively enhance concrete's resilience against sulfate and chemical assaults. Moreover, fly ash's incorporation promotes sustainability by curbing the need for cement production, which is both energy-intensive and emits significant carbon dioxide. This substitution not only reduces greenhouse gas emissions but also conserves natural resources. Nevertheless, the efficacy of FA in concrete can vary based on its chemical composition, fineness, and compatibility with other cementitious materials, necessitating rigorous quality control and precise mix design

Coarse Aggregate

Particles greater than 5 millimeters are known as coarse aggregate, and they are an essential constituent of concrete mixes that provide buildings made of concrete bulk, strength, and stability. Coarse aggregates are materials like gravel, crushed stone, and recycled concrete that are usually obtained from quarries. By acting as the cement paste's skeleton, these aggregates help to form a strong, cohesive matrix. The coarse particles' size, shape, and texture have a major impact on resilience, and longevity of concrete. Higher compressive and tensile strengths may be achieved by using well-graded coarse aggregates with angular or cubical forms because they have superior mechanical and interlocking qualities. Moreover, coarse aggregates with rough surfaces enhance the bond between the aggregate and cement paste, thereby enhancing the overall performance of the concrete. Furthermore, achieving the desired characteristics of concrete, such as workability, pumpability, and resistance to segregation and bleeding, necessitates meticulous selection and proportioning of coarse particles. Reusing recycled aggregates from concrete buildings that have been destroyed is one of the sustainable methods that helps lessen the effect on the environment and preserve natural resource

5. RESULT

CHARACTERISTICS OF STRENGTH AND WORKABILITY

Workability of Concrete

The manageability, placing, and compaction of concrete during construction are crucial for achieving the appropriate structural integrity and appearance. This is known as workability. It encompasses properties including cohesiveness, fluidity, and consistency that affect how readily concrete may be handled and sculpted without separating or bleeding excessively. Workability is determined using techniques such as the flow table test, which measures the spread diameter of self-compacting concrete for fluidity, and the slump test, which measures the settling of a concrete cone to evaluate flow. Achieving optimal workability guarantees efficient building methods, raises the accuracy of placement, and increases the long-term resilience and functionality of concrete structures.

Table 5.1 Workability test on HPC

Mix	FA-0	FA-10	FA-20	FA-30	FA-40	FA-50	FA-60
Compaction Factor (CF) (Decreased by 0.01 for each subsequent mix)	0.97	0.96	0.95	0.94	0.93	0.92	0.91
Slump (mm) (Decreased by 7 mm for each subsequent mix)	85	78	71	64	57	50	43

To improve the workability of the concrete mixture in this investigation, the researchers used a sulphonated naphthalene formaldehyde polymer, namely the SUPAFLO Super Plasticizer. A dose equal to 2% of the total weight of the binder—which included both cement and fly ash—was used to achieve the required degree of workability. In order to guarantee the best flowability and handling comfort during the placing and compaction of concrete, this dose was carefully calculated. The researchers wanted to enhance the rheological characteristics of the concrete mixture by

adding the Super Plasticizer at this precise dose. This would allow for improved flow and consolidation without sacrificing the end product's strength or durability. In concrete technology, this method is often used to maximize workability while preserving the intended mechanical and performance properties of the hardened concrete.

Cube Compressive Strength

Concrete cubes of various ages (3, 7, 28, 56, and 90 days) were subjected to compressive strength tests in the research. The water-binder ratio (0.36) was varied, while fly ash replacement amounts ranged from 10% to 60%. The purpose of these studies was to evaluate how the water-binder ratio and fly ash concentration affected the concrete's ability to gain strength over time. The cube compressive strength findings from these tests are shown in Table 5.2, which offers a thorough summary of the strength performance at various ages and replacement levels. Furthermore, graphical representations of these data are provided in Figures 5.1, which provide visual analysis and comparison of the strength patterns across the designated curing periods.

Table 5.2 Fly ash with an average compressive strength at a water-binder ratio of 0.36.

	FA-0	FA-10	FA-20	FA-30	FA-40	FA-50	FA-60	FA-70	FA-80	FA-90
Fly Ash %	0	11	21	31	41	51	61	71	81	91
3 days	33.76	31.37	29.84	26.92	23.57	19.98	17.93	15.76	13.85	11.97
7 days	42.15	43.24	38.52	36.01	28.99	25.78	20.89	18.92	16.45	14.31
28 days	61.12	59.78	55.76	53.47	47.92	39.95	37.84	33.67	30.81	27.92
56 days	64.22	65.1	59.93	57.82	53.78	50.22	46.99	42.11	38.22	35.09
90 days	66.25	68.12	61.98	60.15	59.31	58.48	54.01	49.98	45.76	41.83

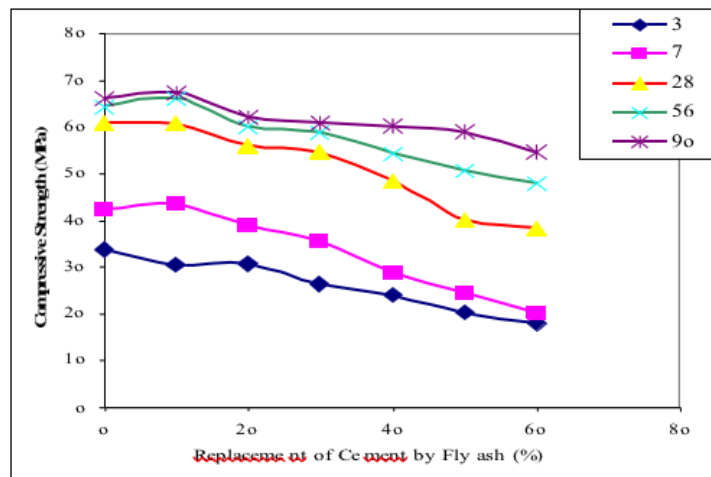


Figure 5.1 Changes in compressive strength as cement is substituted with fly ash

According to the test findings, the fly ash mix FA-10, which has a water-binder ratio of 0.36 and 10% fly ash, had the maximum compressive strength in all age groups. Its performance after 90 days was similar to the control mix, even though it contained more than 60% fly ash, a strong pozzolanic component. However, because the pozzolanic process is slow, this resemblance was not noticeable at earlier ages. This technique plugs big capillary gaps effectively, increasing strength and impermeability, releases heat gradually and builds strength, and depletes rather than produces lime, making the hydrated paste less resistant to acidic surroundings.

FA-11 is the blend with the maximum compressive strength, as shown in Table 5.2. Mixtures FA-61, FA-51, FA-41, and FA-31 differ considerably from control mixes at early ages (3, 7, and 28 days). All combinations do, however, reach compressive strengths of between 50 and 60 MPa after 90 days. Pozzolanic activity is primarily responsible for the latter stages' growth of strength. Strength falls as a percentage with increasing fly ash concentration. It achieves its highest point of 46% at 3 days, its maximum of 37% at 28 days, and its maximum of 18% at 90 days. Fly ash blends show a diminishing strength % reduction with age, as well as stronger development that approaches control mix values. A higher fly ash percentage in the cement eventually produces the required strength, as shown in Figure 5.1. Mixtures FA-11,

FA-21, FA-31, FA-41, FA-51, and FA-61 have a higher variation in compressive strength at three and seven days. The

compressive strength variations with increasing fly ash concentration have, however, reduced dramatically after 28, 56, and 90 days, resulting in a tighter band.

Compressive strength increases with increased cement content at the right ages, but it decreases dramatically with decreased cement content. The compressive strength at 28, 56, and 90 days exhibits little change with increasing cement concentrations, as seen in Figure 5.1.

Figure 5.2 illustrates how the age logarithm values, independent of age, influence compressive strength.

The reason why the mixes' compressive strength increases with time is because fly ash's pozzolanic reactivity contributes significantly to the strength of concrete later on. The enhanced strength of the fly ash blends contributes to their remarkable performance qualities, which enable them to fulfill criteria even at later ages.

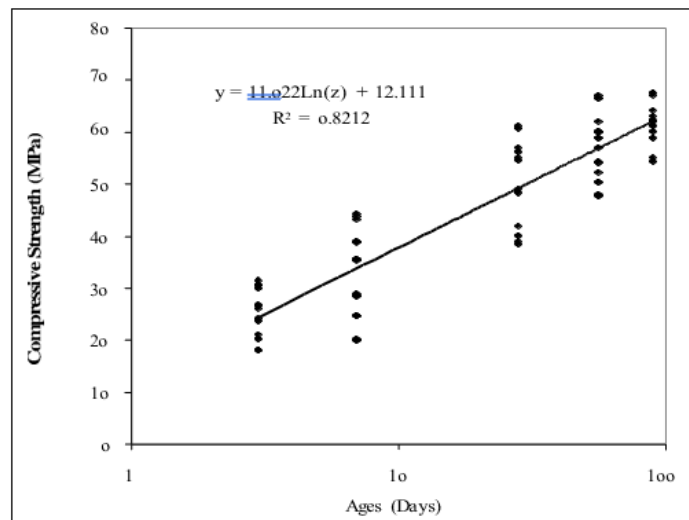


Figure 5.2 The correlation between changes in strength at compression and the duration of concrete's use

The differences in concrete strength are mostly determined by the cement to total aggregate (C/TA) ratio. As seen in Figures 5.3 to 5.7, strength has been observed to increase with a greater C/TA ratio. An increase in the C/TA ratio leads to a larger cement content, which improves compressive strength. This experiment indicates that the maximum strength is mostly caused by a cement concentration of 70%.

Age (days)	3	7	28	56	90
Regression Equation	fck =94.178TAC +6.688	fck =145.01TAC +3.3449	fck =148.52TAC +20.598	fck =109.79TAC +34.681	fck =69.493TAC +47.294
R2	0.9773	0.9478	0.9372	0.9253	0.8664

In the given context, fck denotes the compressive strength measured in megapascals (MPa), while CTA stands for the ratio of Cement to Total Aggregate.

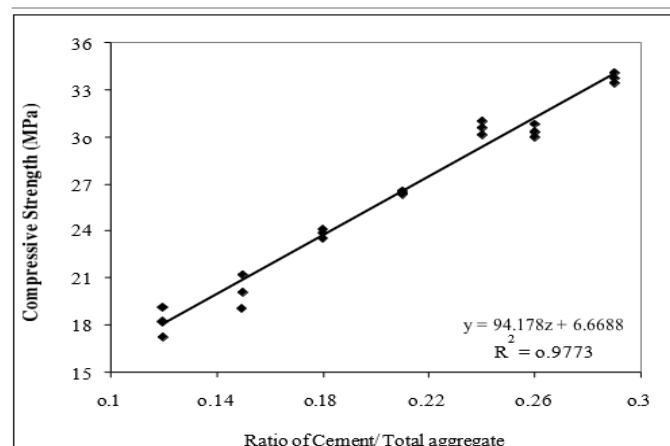


Figure 5.3 The variations in strength at compression over three days with respect to the cement to overall aggregate (C/TA) ratio

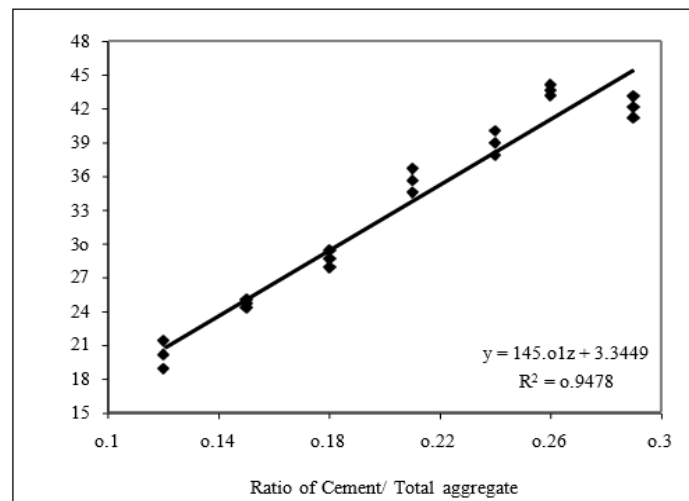


Figure 5.4 shows how the compressive strength changes over a period of seven days in relation to the cement to overall aggregate (C/TA) ratio.

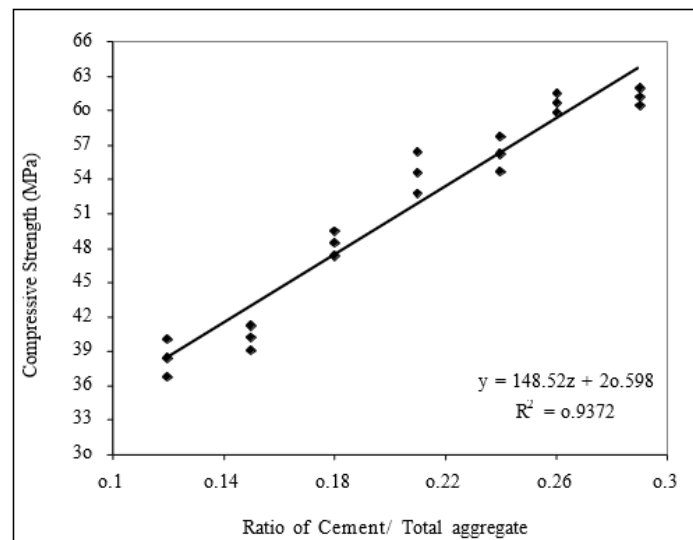


Figure 5.5 The change in strength at compression at 28 days as a function of the cement to overall aggregate (C/TA) ratio.

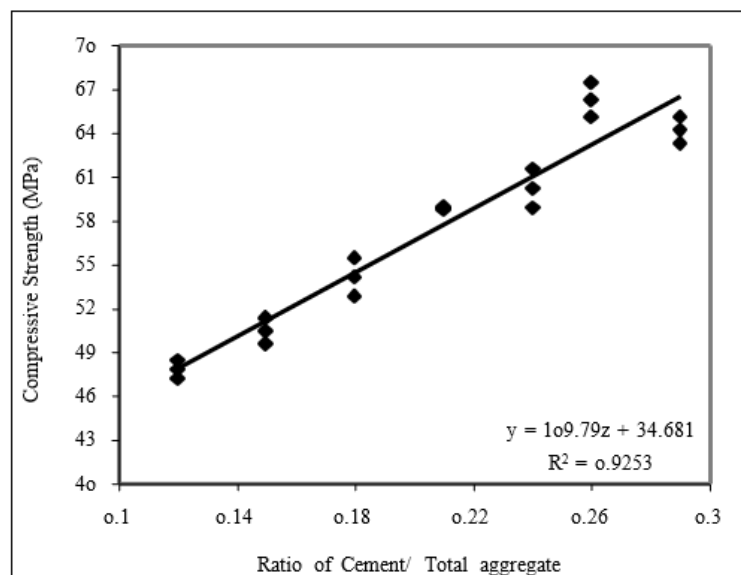


figure 5.6 the variations in strength at compression at 56 days with respect to the cement relative to the total aggregate (C/TA) ratio.

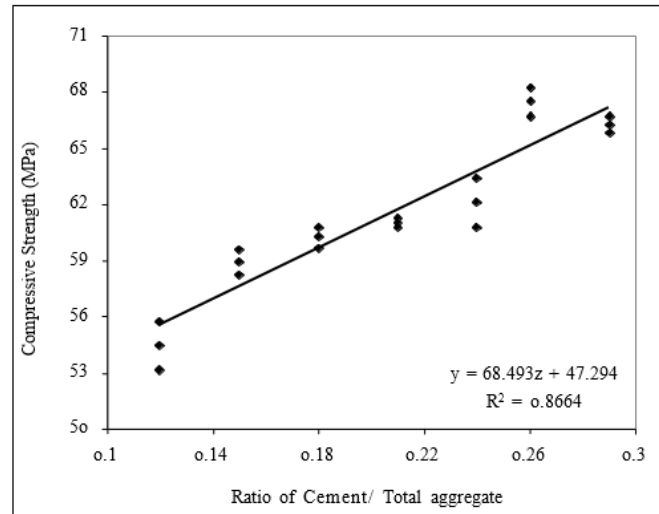


Figure 5.7 The changes in strength at compression after 90 days as a function of the Cement to Overall Aggregate (C/TA) ratio.

Table 5.3's findings show that at 7, 56, and 90 days, concrete mixes containing different amounts of fly ash (FA) reached strength levels comparable to those of a reference mix. Age-related increases in strength ratios in concrete suggest that fly ash blends have become more effective over time. All blends reached 80% of the intended strength after 90 days. FA-11, FA-21, and FA-31 reached 90% strength at 28 days. On the other hand, mixes containing more than 41% fly ash initially had lower strength ratios but, after 90 days, achieved 80% of the goal strength. This illustrates the intricate relationship between fly ash proportions and the evolution of concrete strength, indicating that while high fly ash concentration may temporarily impair early strength, it does not impact long-term performance.

Table 5.3 Strength ratio as a function of concrete age

Sample	3 days	7 days	28 days	56 days	90 days
FA-10	0.88	1.02	0.97	1	0.99
FA-20	0.89	0.9	0.9	0.92	0.92
FA-30	0.76	0.82	0.87	0.9	0.9
FA-40	0.7	0.66	0.77	0.82	0.89
FA-50	0.58	0.57	0.64	0.77	0.87
FA-60	0.52	0.46	0.61	0.72	0.8

5. CONCLUSION

Conclusions are drawn from the analysis conducted across three phases of investigations:

1. The experimental investigations encompassed a thorough examination of the strength characteristics of low and high-volume FA concrete.
2. Strength at compression, split tensile strength, flexural strength at flexure were the focal points of the study, analyzed across various mix compositions.
3. Fly ash content ranging from 0% to 60% was explored to understand its influence on mechanical performance.
4. Testing was conducted at different curing ages spanning from 3 to 90 days, providing insights into the evolution of strength over time.
5. Higher concentrations of fly ash generally correlated with enhanced compressive strength, particularly evident at later curing ages.
6. However, nuanced variations were observed across different mix compositions, highlighting the complex relationship between material composition and mechanical behavior.
7. Split tensile strength exhibited similar trends, with varying degrees of influence from fly ash content and curing age.
8. Strength at flexure, or rupture moduli, demonstrated enhanced features at later curing ages, indicating the potential

for long-term structural integrity.

9. Predictive equations were explored to evaluation of strength at flexure based on strength at compression , revealing discrepancies between observed and predicted values.

10 Existing models, such as those outlined in IS 456 - 2000 and ACI 363-R (1997), showed deviations from observed results, emphasizing the need for further refinement.

11. The findings underscored the importance of continued research to enhance predictive models and refine concrete mix designs.

12. By optimizing fly ash content and mix compositions, concrete structures can be engineered to achieve desired mechanical properties while reducing environmental impact.

13. The study contributes valuable insights for practitioners and researchers alike, guiding the development of more sustainable and resilient concrete infrastructure.

14. It highlights the potential of FA as an accompanying binder, offering opportunities for enhancing both performance and sustainability.

15. Future research directions may include further investigations into the influence of curing conditions, aggregate types, and other additives on concrete properties.

16. Collaboration between academia, industry, and regulatory bodies is essential to foster innovation and widespread adoption of fly ash concrete.

17. The findings have implications for an extensive assortment of use, from residential construction to numerous construction projects.

18. By leveraging the inherent properties of FA, concrete can be engineered to meet the evolving demands of modern construction while minimizing environmental footprint.

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