International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 11 | Nov 2026 www.irjet.net p-ISSN: 2395-0072

A Review on the Effect of Partial Replacement of Cement with Fly Ash on Fresh and Hardened Properties of Concrete

Ayush Kumar Dwivedi[1], DR. DK. Jain[2]

[1]*M. Tech. Scholar, Department of Civil Engineering, Rewa Engineering College, Madhya Pradesh, India*
[2]*Professor, Department of Civil Engineering, Rewa Engineering College, Madhya Pradesh, India*

Abstract - *The increasing demand for concrete in the construction industry has resulted in the extensive consumption of ordinary Portland cement (OPC). Cement manufacturing requires a considerable amount of energy and contributes to carbon dioxide emissions, which have become major environmental concerns. To reduce the environmental impact associated with cement production, the utilization of supplementary cementitious materials as partial replacements for cement has gained significant attention. Fly ash is one of the most commonly used supplementary cementitious materials, obtained as a by-product from coal-based thermal power plants. Its utilization in concrete provides an opportunity to reduce cement consumption and improve the sustainability of construction materials. This review paper presents a comprehensive discussion of previous research investigations on the use of fly ash as a partial replacement of cement in concrete. The review focuses on the influence of fly ash on fresh and hardened properties, particularly workability, compressive strength and bond strength between reinforcing steel and concrete. Different research studies have investigated the effects of fly ash replacement on concrete performance under varying mixture proportions and curing conditions. The incorporation of fly ash may improve the workability of fresh concrete due to its fine particles and generally spherical shape, which can reduce internal friction between cementitious particles. However, its influence on compressive strength depends on the replacement percentage, water-to-cementitious material ratio, fineness, chemical composition and curing age. At higher replacement levels, early-age strength may decrease because of the slower pozzolanic reaction, whereas continued curing can contribute to later-age strength development. The bond strength between reinforcing steel and concrete is also influenced by the mechanical properties of the concrete matrix, reinforcement characteristics, embedment length and interfacial transition zone. The findings of previous researchers indicate that the performance of fly ash concrete should be evaluated by considering fresh and hardened properties together. This review also identifies research gaps related to the combined assessment of workability, compressive strength and reinforcement bond strength, particularly for M30-grade concrete.*

Keywords: Fly Ash, Partial Replacement of Cement, Concrete, Workability, Slump Test, Compressive Strength, Bond Strength, Reinforced Concrete, M30 Grade Concrete.

I. INTRODUCTION

Concrete is one of the most widely used construction materials in the world because of its versatility, strength, durability and cost-effectiveness. It is extensively used in buildings, bridges, roads, dams, tunnels and other infrastructure projects. The major ingredients of conventional concrete are cement, fine aggregate, coarse aggregate and water. Among these materials, cement acts as the primary binding material and plays an important role in developing the strength and durability of concrete.

Ordinary Portland cement is manufactured through a process that involves the extraction of raw materials, crushing, heating and grinding. The production process requires considerable energy and releases carbon dioxide into the atmosphere. The increasing demand for cement due to rapid urbanization and infrastructure development has raised concerns about environmental pollution, energy consumption and the depletion of natural resources. Therefore, researchers and engineers have been investigating alternative materials that can partially replace cement without adversely affecting the required properties of concrete.

One of the important materials considered for this purpose is fly ash. Fly ash is a finely divided powder obtained from the combustion of pulverized coal in thermal power plants. It is collected from flue gases using suitable dust collection systems. Fly ash generally contains silica, alumina, iron oxide and calcium oxide, which influence its physical and chemical characteristics. Due to the presence of reactive silica and alumina, fly ash can exhibit pozzolanic properties and can be used as a supplementary cementitious material in concrete.

The use of fly ash as a partial replacement of cement has gained importance because it can reduce the quantity of cement required in concrete production and provide a useful application for industrial by-products. The incorporation of fly ash may also influence the fresh and hardened properties of concrete. Its fine particle size and generally spherical shape can improve the flow characteristics of fresh concrete under suitable conditions. In hardened concrete, the pozzolanic reaction may contribute to the formation of additional cementitious products and influence the strength development at later ages.

The performance of fly ash concrete is affected by several parameters, including the percentage of cement replacement, water-to-cementitious material ratio, type and fineness of fly ash, cement characteristics, aggregate properties and curing conditions. The selection of an appropriate replacement percentage is therefore important to achieve the required strength and workability.

Workability is an important property of fresh concrete because it determines the ease of mixing, transporting, placing and compacting the concrete. The slump test is commonly used to evaluate the consistency of fresh concrete. A suitable level of workability is necessary to ensure proper compaction and reduce the possibility of honeycombing and segregation.

Compressive strength is one of the principal mechanical properties of hardened concrete. It indicates the ability of concrete to resist compressive loads and is commonly determined by testing standard cube or cylinder specimens at specified curing ages. The strength development of fly ash concrete may differ from conventional concrete because fly ash generally reacts more slowly than Portland cement during the early stages of hydration.

Another important property in reinforced concrete structures is the bond strength between reinforcing steel and concrete. Bond strength provides the mechanism through which stresses are transferred between steel reinforcement and the surrounding concrete. It is influenced by the concrete strength, reinforcement diameter, surface characteristics of the bar, embedment length, concrete cover and confinement conditions. A reduction in bond performance can affect the structural behaviour of reinforced concrete members.

Several researchers have investigated the use of fly ash and other supplementary cementitious materials in concrete. Their studies have examined workability, strength development, durability, reinforcement bond behaviour and the microstructure of cementitious materials. The present review discusses the findings of these investigations and identifies the important factors affecting the performance of fly ash concrete.

II. RESEARCH MOTIVATION

The increasing use of cement in construction has created a need for sustainable construction materials that can reduce environmental impact while maintaining the required engineering performance. The use of industrial by-products as supplementary cementitious materials is considered an effective approach for reducing the consumption of ordinary Portland cement. Fly ash is particularly important because it is generated in large quantities by coal-based thermal power plants and can be utilized in concrete production.

Previous research has shown that the incorporation of fly ash can influence several properties of concrete. However, the influence is not always uniform and depends on the replacement percentage, water content, material characteristics and curing conditions. Some investigations have reported improvements in workability due to the particle characteristics of fly ash, whereas other studies have highlighted the possibility of reduced early-age strength at higher replacement levels.

The development of compressive strength in fly ash concrete is strongly associated with the hydration of cement and the subsequent pozzolanic reaction. At early ages, the replacement of cement with fly ash may reduce the quantity of rapidly reacting cementitious material. With increasing curing age, the reactive components of fly ash can contribute to the formation of additional cementitious compounds. Therefore, the evaluation of strength at different curing ages is important for understanding the performance of fly ash concrete.

Bond strength is also an important consideration because concrete structures frequently contain reinforcing steel bars. The interaction between reinforcement and concrete determines the effective transfer of stresses and contributes to the overall structural performance. Although different studies have investigated reinforcement bond behaviour in high-volume fly ash concrete and other blended cementitious systems, the relationship between fly ash replacement, compressive strength and bond strength requires further investigation.

The motivation of this review is to bring together the findings of previous researchers and understand the influence of fly ash on the fresh and hardened properties of concrete. Particular emphasis is given to workability, compressive strength and reinforcement bond strength. The review also provides a background for further experimental investigations on M30-grade concrete incorporating different percentages of fly ash as a partial replacement of cement.

III. FLY ASH AS A SUPPLEMENTARY CEMENTITIOUS MATERIAL

Fly ash is a finely divided inorganic material obtained from the combustion of pulverized coal in thermal power plants. It is collected from the exhaust gases through electrostatic precipitators or other collection systems. The properties of fly ash depend on the source of coal, combustion temperature, collection process and storage conditions.

The major chemical constituents of fly ash generally include silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3) and calcium oxide (CaO). The presence of these compounds influences its pozzolanic and cementitious characteristics. Fly ash particles are generally finer than many conventional cementitious particles and may have a spherical shape, although the particle characteristics vary with the source.

According to ASTM C618, fly ash is broadly classified into Class F and Class C based on its chemical composition and characteristics. Class F fly ash generally contains lower calcium content and primarily exhibits pozzolanic behaviour. Class C fly ash generally contains higher calcium content and may exhibit both pozzolanic and cementitious properties.

When fly ash is used as a partial replacement of cement, it can influence the concrete matrix through physical and chemical mechanisms.

Filler Effect: Fine fly ash particles can occupy spaces between cement particles and improve the packing characteristics of the cementitious system. This may contribute to a more compact particle arrangement.

Pozzolanic Reaction: The reactive silica and alumina present in fly ash can react with calcium hydroxide released during cement hydration in the presence of water. This reaction produces additional cementitious compounds, which may contribute to strength development and matrix densification.

Particle Shape Effect: The generally spherical shape of fly ash particles can reduce friction between particles and influence the flow characteristics of fresh concrete. This effect may improve workability under suitable mixture conditions.

The performance of fly ash as a cement replacement depends on its fineness, chemical composition, loss on ignition, replacement percentage and compatibility with other concrete ingredients. Therefore, proper characterization of fly ash is important before its use in structural concrete.

IV. EFFECT OF FLY ASH ON WORKABILITY OF CONCRETE

Workability is defined as the property of fresh concrete that determines the ease with which it can be mixed, transported, placed and compacted without segregation or excessive bleeding. It is an important parameter because inadequate workability can create difficulties during construction and may result in improper compaction.

The slump test is one of the commonly used methods for evaluating the consistency of fresh concrete. In this test, fresh concrete is placed in a standard slump cone in layers and compacted according to the prescribed procedure. After lifting the cone vertically, the decrease in height of the concrete is measured as the slump value.

The incorporation of fly ash can influence the workability of concrete because of its particle size, shape and surface characteristics. Fly ash particles are generally spherical, which may produce a ball-bearing effect between cementitious particles. This effect can reduce internal friction and improve the flow characteristics of fresh concrete.

The workability of fly ash concrete is also influenced by the replacement percentage. Depending on the characteristics of the fly ash, the addition of a suitable quantity may improve the consistency of the mixture. However, the effect may vary when fly ash contains higher quantities of unburnt carbon or has different fineness characteristics.

The water-to-cementitious material ratio is another important factor affecting workability. An increase in water content generally increases slump, but excessive water can adversely affect the strength and durability of concrete. Therefore, workability should be achieved through suitable mixture proportions rather than uncontrolled addition of water.

Chemical admixtures such as water reducers and superplasticizers may also influence the workability of fly ash concrete. Their effectiveness depends on the compatibility between cement, fly ash and the admixture.

Previous research on concrete and cementitious mixtures has highlighted the importance of particle characteristics, mixture proportions and admixture dosage in controlling fresh properties. Therefore, the workability of fly ash concrete should be evaluated at different replacement levels under controlled conditions.

V. EFFECT OF FLY ASH ON COMPRESSIVE STRENGTH

Compressive strength is one of the most important properties of concrete and represents its ability to resist compressive loading. It is generally determined by applying an axial compressive load to a standard concrete cube or cylinder specimen until failure occurs. The compressive strength is calculated by dividing the maximum applied load by the loaded surface area of the specimen.

The compressive strength of concrete containing fly ash depends on several parameters, including the percentage of cement replacement, water-to-cementitious material ratio, cement content, fly ash fineness, curing conditions and testing age.

At early ages, the replacement of cement with fly ash may reduce compressive strength because the pozzolanic reaction of fly ash generally develops more slowly than the hydration reaction of Portland cement. When a significant quantity of cement is replaced, the amount of rapidly hydrating cement is reduced. As a result, the early development of strength may be slower.

At later ages, the reactive silica and alumina in fly ash can react with calcium hydroxide to form additional cementitious compounds. These compounds may contribute to the development of a denser matrix and improve the mechanical properties of concrete. The extent of improvement depends on the quality of fly ash, replacement percentage and curing conditions.

The curing period is particularly important for fly ash concrete. Adequate moisture and suitable temperature conditions support cement hydration and the subsequent pozzolanic reaction. Insufficient curing may restrict the development of additional cementitious products and adversely affect strength.

The optimum fly ash replacement percentage cannot be generalized for all concrete mixtures. It varies with the properties of cement and fly ash, aggregate characteristics, water-to-binder ratio and the required concrete grade. Therefore, the strength performance should be evaluated through experimental investigations at specified curing ages.

VI. EFFECT OF FLY ASH ON BOND STRENGTH OF CONCRETE

Bond strength is the ability of concrete to transfer stresses to reinforcing steel through adhesion, friction and mechanical interlocking. It is essential for reinforced concrete structures because the interaction between steel and concrete enables both materials to act together under applied loads.

The bond between reinforcing steel and concrete develops through three major mechanisms. Chemical adhesion develops at the contact surface between steel and cement paste. Friction provides resistance to relative movement between the reinforcement and surrounding concrete. Mechanical interlocking develops due to the ribs and surface deformations present on reinforcing bars.

The bond strength of reinforced concrete is influenced by the compressive strength of concrete, diameter of reinforcing bars, surface characteristics of reinforcement, embedment length, concrete cover, confinement and curing conditions.

The incorporation of fly ash can influence bond performance by modifying the cementitious matrix and the interfacial transition zone. The pozzolanic reaction of fly ash may contribute to matrix densification at later ages. However, the effect on reinforcement bond strength depends on the replacement percentage and the strength development of the concrete.

The pull-out test is commonly used to evaluate the bond between reinforcing steel and concrete. In this method, a reinforcing bar is embedded in a concrete specimen and subjected to an axial tensile load. The maximum load and the corresponding slip or failure behaviour are recorded to assess bond performance.

The average bond stress in a pull-out specimen is commonly calculated using the relationship:

$$tau_{bd}=pi\ dl$$

Where:

- (tau_{bd}) = Average bond stress (MPa)
- (P) = Maximum applied pull-out load (N)
- (d) = Diameter of reinforcing bar (mm)
- (l) = Embedded length of reinforcing bar (mm)

The relationship between compressive strength and bond strength is important, but bond performance cannot be determined only from compressive strength. Reinforcement geometry, embedment length, concrete cover and confinement also influence the test results.

Previous researchers have investigated the bond behaviour of high-volume fly ash concrete, blended cementitious systems and high-strength concrete. Their findings provide useful information about the interaction between concrete matrix properties and reinforcement bond performance.

VII. LITERATURE REVIEW

Babu, Kode and Dey (2023) investigated the bond strength of fly ash and silica fume blended concrete mixes. Their research focused on the influence of supplementary cementitious materials on the bond behaviour of concrete. The study considered binary blended concrete mixtures with fly ash replacement levels of 20%, 30% and 40%. Direct pull-out testing was carried out using a Universal Testing Machine (UTM) to evaluate the bond behaviour of the specimens. The investigation considered the influence of blended material proportions on the interaction between reinforcing steel and the surrounding concrete matrix. The findings reported in the supplied literature indicate that bond strength follows the general strength development of the concrete matrix. The study is relevant to understanding how the incorporation of fly ash and silica fume can influence reinforcement bond behaviour. It also highlights the importance of proper curing and mixture proportions when evaluating the bond performance of blended concrete. However, the individual effects of fly ash and silica fume should be distinguished when interpreting the findings.

Naresh, Lavanya and Kumar (2021) investigated the bond strength between normal concrete and high-volume fly ash concrete. The study focused on the interfacial shear and tensile bond behaviour between conventional concrete and high-volume fly ash concrete elements. The investigation provides information about the interaction between two concrete materials having different compositions and mechanical characteristics. The performance of a concrete-to-concrete interface depends on the strength of the individual matrices, surface condition, curing and the quality of the interface. The findings highlighted the importance of mechanical characteristics and suitable curing conditions for obtaining satisfactory interfacial bonding. This study is useful for understanding the bonding behaviour of high-volume fly ash concrete and its application in repair and construction works. However, concrete-to-concrete interfacial bonding is different from reinforcement pull-out bond strength, and both types of bonding should be considered separately in experimental comparisons.

Gomaa, Gheni, Kashosi and ElGawady (2019) studied the bond strength of eco-friendly Class C fly ash-based alkali-activated concrete with Portland cement concrete. Their investigation focused on the interface between fly ash-based alkali-activated concrete and conventional Portland cement concrete. The study evaluated the interfacial bond behaviour and the influence of the characteristics of the two cementitious systems. Fly ash-based alkali-activated materials differ from conventional concrete containing fly ash as a partial replacement of cement because their binder systems and activation mechanisms are different. The research is relevant for understanding the bonding behaviour of alternative cementitious materials and their possible applications in repair and rehabilitation works. The study also demonstrates the importance of interface characteristics when two different concrete systems are connected. Its findings provide supporting information about the role of material composition and surface interaction in developing bond strength, although they should not be directly treated as reinforcement pull-out results for ordinary fly ash concrete.

Arezoumandi, Wolfe and Volz conducted a comparative study of the bond strength of reinforcing steel in high-volume fly ash concrete and conventional concrete. Their investigation included pull-out tests and beam-splice tests to examine the bond performance of deformed reinforcing bars. The study focused on high-volume fly ash concrete containing approximately 50% to 70% fly ash and compared its reinforcement bond behaviour with conventional concrete. The investigation is important because reinforcement bond is one of the essential requirements for the structural application of concrete. The findings reported in the supplied literature indicate that high-volume fly ash concrete can exhibit normalized bond strength comparable to or exceeding that of conventional concrete under the investigated conditions. The study suggests that the use of higher fly ash replacement levels does not necessarily result in poor reinforcement bond performance when the concrete mixture and

curing conditions are properly controlled. This research is particularly relevant to understanding the relationship between concrete strength and steel–concrete bond behaviour.

Islam and Islam (2013) investigated the strength and durability characteristics of concrete made with fly ash blended cement. Their research considered different fly ash replacement levels and examined the performance of concrete over extended curing periods. The investigation is relevant because the strength development of fly ash concrete is influenced by the gradual pozzolanic reaction. The replacement of cement with fly ash may influence early-age strength, while continued curing can contribute to later-age strength development. The study provides useful information about the relationship between fly ash content, curing period and the mechanical properties of concrete. The findings indicate that the evaluation of fly ash concrete should not be restricted to early-age testing alone. Later-age strength and durability characteristics are also important for understanding its long-term performance. This study supports the need to consider multiple curing ages while assessing concrete containing fly ash as a partial replacement of cement.

De Larrard and Le Roy (1992) investigated the influence of mixture composition on the mechanical properties of high-performance silica-fume concrete. Their research focused on the relationship between mixture proportions and the mechanical performance of concrete. The study examined how the composition of the cementitious system influences the strength and performance of hardened concrete. Although silica fume was the principal supplementary material considered in this investigation, the work provides useful supporting information about the influence of fine supplementary cementitious materials on concrete properties. The study highlights the importance of particle characteristics, matrix composition and mixture proportions in determining the mechanical behaviour of concrete. Its findings are useful for understanding the general mechanisms through which supplementary cementitious materials can modify the cementitious matrix. However, silica fume and fly ash have different physical and chemical characteristics, and their effects should not be considered identical.

Soroushian et al. (1991) investigated the effect of condensed silica fume on the bond between steel reinforcement and concrete. Their study focused on local bond stress and slip behaviour under different concrete and reinforcement conditions. The investigation is important because the bond between reinforcing steel and concrete determines the transfer of stress between the two materials. The bond performance depends on the mechanical characteristics of the concrete matrix and the interaction between the steel surface and surrounding cement paste. The research highlighted the importance of matrix density and interfacial properties in determining the reinforcement bond behaviour. Although the study focused on silica fume rather than fly ash, it provides supporting information about the influence of supplementary cementitious materials on the steel–concrete interface. The findings are useful for understanding the mechanisms that control reinforcement bond strength and for identifying the parameters that should be considered while conducting pull-out testing.

Gjørv, Monteiro and Mehta (1990) investigated the engineering properties of very-high-performance concrete with reference to its microstructure and macrostructure. Their research examined the relationship between the internal structure of concrete and its engineering performance. The study provides important background information about the influence of supplementary cementitious materials and the interfacial transition zone on concrete properties. The interfacial transition zone is the region surrounding aggregate particles and plays an important role in the mechanical behaviour of concrete. Changes in the microstructure of the cementitious matrix can influence the density, porosity and strength of this region. The research is useful for understanding the relationship between microstructural characteristics and the overall mechanical performance of concrete. Although it is not a direct fly ash reinforcement pull-out study, its findings provide supporting knowledge for explaining the influence of cementitious matrix characteristics on concrete strength and bond behaviour.

De Larrard and Malier investigated the strength of the bond between reinforcement and high-strength concrete. Their research focused on the relationship between concrete matrix characteristics and the bond behaviour of reinforcing steel. The bond between steel and concrete is affected by the mechanical properties of the surrounding concrete, reinforcement surface geometry and the conditions of embedment. The study provides background information about the role of concrete strength and matrix characteristics in the development of reinforcement bond. The investigation is relevant because the bond performance of reinforced concrete is not controlled by the reinforcement alone; the properties of the surrounding concrete matrix also play an important role. The study can be used as supporting literature for understanding the mechanisms of steel–concrete interaction and the importance of evaluating bond behaviour along with compressive strength.

Chapman and Shah (1987) investigated the load–slip behaviour of deformed bars and steel fibres in high-strength concrete. Their research examined the bond characteristics and the relationship between applied load and relative movement at the steel–concrete interface. The load–slip response is an important parameter in understanding the behaviour of reinforcement embedded in concrete. Deformed reinforcing bars develop mechanical interlocking through their surface ribs, while the surrounding concrete provides resistance against the relative movement of the reinforcement. The investigation provides

useful background information about the influence of reinforcement characteristics, concrete strength and curing age on bond behaviour. The study is relevant to the selection and interpretation of reinforcement bond testing methods. Although the research was not specifically focused on fly ash concrete, its findings provide a foundation for understanding the general behaviour of reinforcing steel embedded in concrete.

RILEM/CEB/FIP (1978) provided recommendations for evaluating the bond strength of reinforcement in concrete through standardized experimental procedures. The recommendations describe the principles of bond testing and provide a framework for evaluating the interaction between reinforcing steel and the surrounding concrete. Standardized bond testing is important because the results can be influenced by specimen dimensions, bar diameter, embedment length, loading arrangement and test conditions. The use of a consistent testing procedure helps researchers compare the results obtained from different investigations. These recommendations provide a useful background for selecting suitable experimental procedures and interpreting bond test results. The study is relevant to research involving pull-out behaviour and reinforcement bond performance because it establishes the importance of controlled testing conditions in evaluating the steel–concrete interface.

Baron and Lesage (1973) investigated the fundamental definition of workability in concrete. Their research contributed to the understanding of the behaviour of fresh concrete and the factors influencing its consistency and handling characteristics. Workability is an important property because fresh concrete must possess sufficient consistency to be mixed, transported, placed and compacted properly. The characteristics of cementitious materials, aggregate grading, water content and admixtures influence the workability of concrete. The study provides a theoretical background for understanding the concept of workability and the importance of suitable evaluation methods. It is relevant to investigations involving fly ash concrete because the incorporation of supplementary cementitious materials can modify the flow behaviour and consistency of fresh concrete. The findings support the importance of evaluating workability when comparing concrete mixtures containing different percentages of cement replacement.

VIII. COMPARATIVE DISCUSSION OF PREVIOUS STUDIES

The reviewed research studies indicate that the properties of concrete are influenced by the characteristics and quantity of supplementary cementitious materials. Different investigations have focused on the fresh properties, mechanical strength, reinforcement bond behaviour and microstructure of concrete.

The studies related to fly ash concrete indicate that the replacement of cement with fly ash can influence the workability and strength development of concrete. The effect on workability depends on the fineness, particle shape, replacement percentage and water content. Similarly, the compressive strength of fly ash concrete depends on the amount of cement replaced and the duration of curing.

Research on reinforcement bond behaviour has shown that the bond between steel and concrete is influenced by the mechanical characteristics of the concrete matrix, reinforcement geometry and embedment conditions. Studies on high-volume fly ash concrete provide useful information about the possibility of obtaining satisfactory reinforcement bond performance under suitable mixture and curing conditions.

Some of the reviewed studies have investigated silica fume, alkali-activated concrete and high-strength concrete rather than conventional Portland cement concrete containing fly ash as a partial replacement. These studies provide supporting information about the general behaviour of cementitious matrices and reinforcement interfaces, but their findings should be distinguished from direct fly ash replacement investigations.

The literature also indicates that different bond testing methods evaluate different types of interfaces. Reinforcement pull-out tests evaluate the bond between steel and concrete, whereas concrete-to-concrete shear or tensile tests evaluate the bond between two concrete layers. Therefore, the results of these methods should not be compared as if they represent the same property.

Overall, the previous investigations demonstrate the importance of evaluating workability, compressive strength and bond strength together to understand the performance of concrete containing supplementary cementitious materials.

IX. RESEARCH GAP

Based on the review of previous studies, it is observed that considerable research has been carried out on the use of fly ash and other supplementary cementitious materials in concrete. However, certain aspects require further investigation.

1. The combined influence of different fly ash replacement percentages on workability and compressive strength needs to be evaluated under consistent mixture proportions.
2. Further investigations are required to understand the relationship between compressive strength and reinforcement bond strength in conventional Portland cement concrete containing fly ash.
3. The influence of curing age on the development of compressive strength and reinforcement bond performance requires additional experimental evaluation.
4. More studies are needed to examine the effect of fly ash replacement on the reinforcement pull-out bond behaviour of M30-grade concrete.
5. The influence of reinforcement diameter and embedment length on the bond performance of fly ash concrete can be investigated under controlled conditions.
6. The findings of studies involving silica fume, alkali-activated concrete and conventional fly ash blended concrete should be carefully distinguished while comparing the results of previous research.
7. A combined evaluation of slump, compressive strength and reinforcement bond strength can provide a more comprehensive understanding of the suitability of fly ash concrete for structural applications.

X. FUTURE SCOPE

Future investigations may focus on the performance of M30-grade concrete incorporating fly ash as a partial replacement of cement. Different replacement percentages can be considered to understand their influence on fresh and hardened properties.

The experimental programme may include slump testing to evaluate workability, compressive strength testing at selected curing ages and pull-out testing to determine the bond between reinforcing steel and concrete. The influence of curing conditions, water-to-binder ratio, reinforcement diameter and embedment length may also be considered.

The relationship between compressive strength and bond strength can be examined to understand whether changes in the concrete matrix are reflected in the reinforcement bond performance. The results may help in identifying suitable fly ash replacement levels for producing concrete with satisfactory workability and mechanical properties.

Further studies may also include microstructural investigations to understand the influence of fly ash on the interfacial transition zone and the development of cementitious products. Such investigations can provide additional information about the mechanisms responsible for changes in strength and bond performance.

XI. CONCLUSION

The present review discusses the influence of fly ash as a partial replacement of cement on the fresh and hardened properties of concrete, with particular emphasis on workability, compressive strength and reinforcement bond strength.

The review indicates that fly ash is an important supplementary cementitious material that can contribute to sustainable concrete production by reducing cement consumption and utilizing industrial by-products. Its physical and chemical characteristics influence the properties of fresh and hardened concrete.

The incorporation of fly ash can influence the workability of fresh concrete because of its fine particles and generally spherical shape. However, the actual effect depends on the fineness, replacement percentage, water content and other mixture characteristics.

The compressive strength of fly ash concrete is influenced by the replacement percentage and curing period. Higher replacement levels may reduce early-age strength due to the slower pozzolanic reaction. Continued curing can contribute to later-age strength development through the formation of additional cementitious compounds.

The bond strength between reinforcing steel and concrete is influenced by the strength of the concrete matrix, reinforcement characteristics, embedment length, confinement and interfacial properties. Previous investigations on high-volume fly ash concrete indicate that satisfactory reinforcement bond performance can be achieved under suitable conditions.

The reviewed studies also demonstrate that the behaviour of concrete containing different supplementary cementitious materials should be evaluated according to the type of material and testing method. Studies involving silica fume, alkali-activated concrete and concrete-to-concrete interfaces provide useful supporting information but should not be treated as direct evidence for conventional fly ash cement-replacement concrete.

Overall, the use of fly ash as a partial replacement of cement has potential environmental and engineering benefits. However, its suitability for structural concrete should be established through systematic evaluation of fresh and hardened properties. Further experimental investigations are required to understand the combined influence of fly ash replacement on workability, compressive strength and reinforcement bond strength, particularly in M30-grade concrete.

REFERENCES

1. Babu, K., Kode, V., & Dey, S. (2023). Bond Strength of Fly Ash and Silica Fume Blended Concrete Mixes. **[Journal name, volume, issue, pages and DOI to be confirmed.]**
2. Naresh, Lavanya, & Kumar. (2021). A Study on Bond Strength of Normal Concrete to High Volume Fly Ash Concrete. **[Complete author names, journal name, volume, pages and DOI to be confirmed.]**
3. Gomaa, E., Gheni, A. A., Kashosi, C., & ElGawady, M. (2019). Bond Strength of Eco-Friendly Class C Fly Ash-Based Alkali-Activated Concrete to Portland Cement Concrete. **[Publication details to be confirmed.]**
4. Arezoumandi, M., Wolfe, M. H., & Volz, J. S. A Comparative Study of the Bond Strength of Reinforcing Steel in High-Volume Fly Ash Concrete and Conventional Concrete. **[Publication year and bibliographic details to be confirmed.]**
5. Islam, M. M., & Islam, M. S. (2013). Strength and Durability Characteristics of Concrete Made with Fly-Ash Blended Cement. **[Journal name, volume, issue and page numbers to be confirmed.]**
6. De Larrard, F., & Le Roy, R. (1992). Influence of Mix Composition on Mechanical Properties of High-Performance Silica-Fume Concrete. **[Publication details to be confirmed.]**
7. Soroushian, P., et al. (1991). Effect of Condensed Silica Fume on the Steel-Concrete Bond. **[Complete author names and publication details to be confirmed.]**
8. Gjørv, O. E., Monteiro, P. J. M., & Mehta, P. K. (1990). Engineering Properties of Very-High-Performance Concretes—From Micro- to Macrostructure. **[Publication details to be confirmed.]**
9. De Larrard, F., & Malier, Y. Strength of the Reinforcement–High Strength Concrete Bond. **[Publication year and details to be confirmed.]**
10. Chapman, R. A., & Shah, S. P. (1987). Load-Slip Behavior of Deformed Bars and Steel Fibers in High-Strength Concrete. **[Publication details to be confirmed.]**
11. RILEM/CEB/FIP. (1978). Test of the Bond Strength of Reinforcement of Concrete: Test by Bending. **[Exact standard publication details to be confirmed.]**
12. Baron, J., & Lesage, R. (1973). Proposal for a Definition of Workability. **[Publication details to be confirmed.]**
13. ASTM International. ASTM C618. Standard Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.