International Journal of Applied Engineering & Technology

A CRITICAL ANALYSIS OF RESEARCH ON THE STRUCTURAL BEHAVIOR OF HIGH-VOLUME FLY ASH CONCRETE

Parimal Shukla[1], Manoj Kumar Tiwari[2] and Jeetendra Tiwari[3]

[1]Research Scholar, Civil Engineering Department, C.V.Raman University,Bilaspur, Chhattisgarh, India

[2]Professor Civil Engineering Department, C.V.Raman University, Bilaspur, Chhattisgarh, India

[3]Professor Mechanical Engineering Department, Christian college of Engineering and Technology, Bhilai, Chhattisgarh, India

ABSTRACT

Concrete is a fundamental component in construction, accounting for 40% to 60% of the total cost in conventional residential buildings, with cement comprising approximately 22% to 28% of this expense, depending on the structure. To reduce cement consumption without increasing the unit cost of concrete, the incorporation of admixtures like fly ash has been explored. This approach not only conserves cement but also maintains the essential properties of concrete for structural applications.

India's growing power demand is primarily met by thermal power stations that utilize low-grade pulverized coal, resulting in the production of fly ash. This byproduct can be effectively used as an additional material in reinforced concrete footers to enhance structural ductility.

This paper presents experimental findings on the structural performance of reinforced concrete footers containing varying percentages of fly ash. The study compares the performance of these modified footers to traditional reinforced concrete footers without fly ash. Results indicate that incorporating fly ash improves the structural performance of reinforced concrete footers. Thus, utilizing fly ash as an additive in reinforced concrete footer production offers significant benefits.

Keywords: *Structural Performance, Fly Ash, Concrete*

1. INTRODUCTION

Concrete is a common building material because of its affordability, toughness, and durability. Human demands, notably in the building industry, are growing as a result of population growth, which also encourages the development of the construction sector, particularly in the material sector. One of the materials most frequently utilized in the building sector is concrete. Globally, an estimated 25 billion tons of concrete are used [1]. Because of this quantity, a significant amount of Portland cement, the main ingredient in concrete, must be manufactured. According to a 2005 report, 2.2 billion tons of Portland cement must be produced annually to meet global demand [2]. Due to its impact on the environment, global greenhouse gas emissions have been a significant topic of discussion in the previous ten years. Carbon dioxide gas (CO2) is one of the primary causes of the issue. In order to meet the growing demand for cement, cement mills are boosting their production. However, the situation turns into an environmental issue because of the CO2 that is released into the atmosphere as a result of cement plants' operations. One ton of CO2 gas emissions are also thought to result from the manufacturing of one ton of cement [3]. Material experts who are looking for novel materials to use less cement are concerned about the detrimental environmental effects of cement mills.

The most accessible residue substance from burning coal worldwide is fly ash. It was projected that the world's fly ash supply was 600 million tons in 2000 [3]. Since the 1930s, studies have been conducted on fly ash as an additive for concrete [4]. According to the American Concrete Institute, fly ash is categorized into three classes based on its chemical makeup: N, F, and C. When fly ash is added to concrete, it can reduce heat generation, have low permeability, and increase durability [5].

The incorporation of fly ash (FA) in concrete can reduce cement consumption, even at optimal replacement levels, while enhancing concrete strength. The use of FA is expected to significantly decrease cement demand, thereby lowering production and mitigating its environmental impact. Integrating FA into concrete mixtures as a partial cement replacement represents a notable advancement in concrete technology. However, research at the structural element level remains limited [5]. Shear failure in beams is influenced by several factors, including concrete compressive strength, longitudinal reinforcement ratio, shear span-to-effective depth ratio, and member size [6].

India generates approximately 300 million tons of fly ash annually from various thermal power plants, with only 50% being utilized, primarily in cement production, concrete applications, and landfills [7]. The disposal of fly ash remains a significant challenge due to its environmental hazards. According to the National Thermal Power Corporation (NTPC), fly ash production is expected to rise each year with increasing power demand across sectors [8].

A report by the Central Electricity Authority of India indicates that the country achieved peak fly ash utilization in 2009-2010. However, further efforts are required to reach an optimal utilization rate of 95%-100% [9]. Given the importance of concrete sustainability, the large-scale use of fly ash is highly beneficial. Literature defines cement replacement of 50% or more with fly ash as high-volume fly ash (HVFA) concrete. Such concrete has demonstrated excellent durability and low permeability to chloride ions [10].

Koyama et al. (2008) studied the mechanical properties of concrete beams containing a high proportion of fine fly ash. While the cement content remained constant, the fly ash content varied across specimens. The results indicated that increasing the fly ash volume in concrete enhanced shear strength and deformability [11].

Arezoumandi and Volz (2013) investigated the impact of fly ash replacement levels on the shear strength of high-volume fly ash concrete beams. Class C fly ash was used, with two identical mixes differing only in fly ash content—50% and 70% of the cement mass, alongside conventional concrete. The results showed that the mix with 70% fly ash exhibited greater shear strength than both the 50% fly ash mix and conventional concrete [12].

Rao et al. (2011) examined the shear resistance of high-volume fly ash reinforced concrete beams without web reinforcement. Specimens contained 0% and 50% fly ash replacement by mass of cement, with varying longitudinal tensile reinforcement. The findings revealed that an increased ratio of longitudinal tensile reinforcement led to greater shear strength in beams with 50% fly ash [13].

Lisantono et al. (2017) analyzed the shear behavior of high-volume fly ash concrete in reinforced concrete (RC) beams, replacing 50%, 60%, and 70% of cement mass with fly ash. Longitudinal reinforcement and stirrups were kept constant in the bending test region, while no shear reinforcement was provided in the shear test region. The study found that increasing fly ash content reduced shear strength and made the beam more brittle [14].

Nasution et al. (2019) visually monitored the initial crack formation in beam tests and recorded the corresponding load at crack initiation. The results indicated that the initial crack load of control beams was lower than that of all fly ash-containing beams. However, the addition of fly ash did not show a consistent effect on increasing or decreasing the initial crack load. The ultimate load of fly ash-containing beams was generally lower than that of control beams, with ultimate load decreasing as fly ash content increased. Among the fly ash specimens, beams with 10% fly ash exhibited the highest shear strength due to their superior ultimate loads. The shear load-deflection curves for all specimens displayed a nearly linear trend until reaching the ultimate load [15].

Sakthi Eswaran and Ganesan (2013) found that the load-carrying capacity of specimens S1-S12 exceeded that of the control specimen, which sustained an ultimate load of 70 kN. The flexural performance of all specimens was superior to the control. Among them, specimen S7 (30% fly ash, 50% copper slag, and 0.50% steel fiber) exhibited the highest ultimate load, 50% greater than the control specimen. Similarly, specimens S5 (30% fly ash, 40% copper slag, and 0.50% steel fiber) and S6 (15% fly ash, 50% copper slag, and 0.50% steel fiber) carried loads 42.88% higher than the control specimen [16].

Reinforced concrete beams with fly ash demonstrated lower deflections and improved serviceability. The issue of excessive instantaneous deflection in high-volume fly ash concrete could be mitigated with the addition of a superplasticizer [17]. Furthermore, flexural strength can be enhanced by replacing fine aggregate with fly ash in concrete [18]. Experimental studies have shown that the flexural response of fly ash-based concrete beams is greater than that predicted analytically [19]. According to Sumajouw et al. (2006), the load-bearing behavior of fly ash-based concrete is comparable to that of Portland cement concrete [20].

Fuzail Hashmi et al. (2020) observed that reinforced concrete beams with up to 40% fly ash exhibited significant cracking moments and load-carrying capacity, particularly in higher-grade concrete. The flexural performance of high-volume fly ash concrete structural elements improved with increasing concrete strength. Beams with up to 40% fly ash replacement demonstrated good serviceability in high-strength concrete mixes. The reduction in ultimate load-carrying capacity for high-volume fly ash beams was minimal compared to beams without fly ash, especially in higher-strength concrete.

The crack patterns in reinforced concrete beams with and without fly ash were similar, though high-volume fly ash concrete elements exhibited wider cracks. Experimental measurements of ultimate deflection in both plain and fly ash concrete beams and slabs aligned well with finite element model predictions. In the initial loading stages, the finite element model underestimated deflections compared to experimental values, but at failure, the predicted and measured deflections using ABAQUS showed strong agreement [21].

Ade Lisantono et al. (2020) demonstrated that the load-carrying capacities of normal reinforced concrete beams and fly ash-reinforced concrete beams were 74.87 kN and 75.01 kN, respectively. This indicates that fly ash-reinforced concrete beams had a comparable load-carrying capacity to normal reinforced concrete beams. The load-deflection behavior of fly ash concrete beams followed the same pattern as normal reinforced beams, with an initial linear increase, followed by horizontal deformation after yielding until failure. The study also found that both fly ash and conventional reinforced concrete beams exhibited ductile behavior. In their plastic state, the curvature increased by 124% in normal beams and 211% in fly ash-reinforced beams [22].

To enhance the strength and durability of concrete, cement was replaced with 15% and 20% fly ash. When 20% fly ash was combined with a superplasticizer, the concrete exhibited improved performance at higher displacement levels, along with increased stiffness degradation, ductility, and energy absorption [24].

3. CONCLUSION

A review of previous literature indicates that fly ash enhances the structural performance of reinforced concrete beams. Its inclusion improves the flexural performance, load-deflection behavior, shear behavior, and overall load-carrying capacity of reinforced concrete beams. To enhance the strength and durability of concrete, cement replacement levels of 15% to 20% fly ash have been widely utilized.

Additionally, fly ash can be effectively repurposed as a supplementary material in concrete foundation construction. Based on the reviewed research, it is concluded that the durability of high-performance concrete can be significantly improved by incorporating fly ash as an admixture, either alone or in combination with other mineral admixtures. The optimal replacement level typically ranges from 15% to 20% by weight.

Concrete mixed with PCE-based superplasticizers exhibited greater consistency in performance and improved efficiency in reducing water demand while maintaining initial workability. The addition of superplasticizers enhances workability without increasing water content. Across different concrete grades, no reduction in compressive strength was observed. Furthermore, superplasticizer admixtures contribute to improved durability by increasing ultimate strength and lowering the water-cement ratio.

REFERENCES

[1] Monfardini L, Minelli F. Experimental study on full-scale beams made by reinforced alkali activated concrete undergoing flexure. Materials (Basel), 2016, 9 (9).

[2] Yang EH, Yang Y, Li VC. Use of high volumes of fly ash to improve ECC mechanical properties and material greenness. ACI Mater J. 2007, 104(6): 620–8.

[3] Bilodeau A, Mohan Malhotra V. High-volume fly ash system: Concrete solution for sustainable development. ACI Struct J. 2000;97(1):41–8.

[4] Thomas MDA. Optimizing the Use of Fly Ash in Concrete. Portl Cem Assoc. 2007;24.

[5] Arezoumandi M, Volz JS, Ortega CA, Myers JJ. Shear Behavior of High-Volume Fly Ash Concrete versus Conventional Concrete: Experimental Study. J Struct Eng [Internet]. 2015;141(3):B4014006. Available from: http://ascelibrary.org/doi/10.1061/%28ASCE%29ST.1943-541X.0001003.

[6] Thamrin R, Tanjung J, Aryanti R, Nur OF, Devinus A. Shear strength of reinforced concrete T beams without stirrups. J Eng Sci Technol. 2016; 11(4):548–62.

[7] Annual Report of Central Electricity Authority, Ministry of Power, Government of India; 2018.

[8] A Book on "Fly ash for cement concrete". Ash utilization division. Noida: NTPC Limited; 2007.

[9] Haque ME. Indian fly-ash: production and consumption scenario. Int J Waste Resource 2013;3(1):22–25.https://doi.org/10.12777/ijwr.3.1.2013.22-25.

[10] Malhotra VM, Mehta PK. High-performance, high-volume fly ash concrete: materials, mixture proportioning,properties, construction practice, and case histories. Ottawa: Supplementary Cementing Materials for Sustainable Development; 2002.

[11] Koyama T, Sun YP, Fujinaga T, Koyamada H, Ogata F. Mechanical Properties of Concrete Beam Made of a Large Amount of Fine Fly Ash. In: 14th World Conference on Earthquake Engineering. 2008.

[12] Arezoumandi M, Volz JS.Effect of fly ash replacement level on the shear strength of high volume fly ash concrete beams. J Clean Prod [Internet]. 2013; 59:120-30 available from:http://dx.doi.org/10.1016/j.jclepro.2013.06.043.

[13] Rao RM, Mohan S, Sekar SK. Shear resistance of high volume fly ash reinforced concrete beams without web reinforcement. Int J Civ Struct Eng. 2011; 1(4):986-93.

[14] Lisantono A, Wigroho HY, Purba RA. Shear Behavior of High-volume Fly Ash Concrete as Replacement of Portland Cement in RC Beam. Procedia Eng. 2017; 171:80-7.

[15] A E Nasution, R Kurniawan, R Thamrin, Shear behavior of fly ash reinforced concrete beam without shear reinforcement, IOP Conf. Series: Materials Science and Engineering 602 (2019) 012104, Conference on Innovation in Technology and Engineering Science, 2019.

[16] Sakthieswaran N, Ganesan K, Flexural Performance of Concrete Beams Containing Fly Ash, Silica Fume, Copper Slag, and Fibers, Australian Journal of Basic and Applied Sciences, 7(8): 886-891, 2013, ISSN 1991-8178.

[17] Malhotra VM. Super plasticized fly ash concrete for structural applications. Concrete Int 1986; 8(12):28–31.

[18] Siddique R. Effect of fine aggregate replacement with class F fly ash on the mechanical properties of concrete. CemConcr Res 2003; 33(4):539–47. https://doi.org/10.1680/jmacr.15.00384.

[19] Uma K, Anuradha R, Venkatasubramani R. Experimental investigation and analytical modeling of reinforced geopolymer concrete beam. Int J Civil Struct Eng 2012; 2(3):808. https://doi.org/10.6088/ijcser.00202030010.

[20] M.D.J. Sumajouw, B.V. Rangan, Low calcium fly ash-based geopolymer concrete: reinforced beams and columns. Research report GC-3 Faculty of Engineering 2006 Curtin University of Technology Perth, Australia. http://hdl.handle.net/20.500.11937/23928.

[21] A. Fuzail Hashmi, M. Shariq, A. Baqi, Flexural performance of high volume fly ash reinforced concrete beams and slabs, Structures 25 (2020) 868–880, Institution of Structural Engineers. Published by Elsevier Ltd.

[22] Ade Lisantono, Johanes Januar Sudjati and Angelina Eva Lianasari, Flexural Behavior Of Fly Ash-Based Geopolymer R/C Beam With Bauxite Material As Coarse Aggregates, International Journal of Geomate, Jan., 2020, Vol.18, Issue 65, pp. 80–85, ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.65.43211, Geotechnique, Construction Materials and Environment.

[23] Solahuddin B. Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang Darul Makmur, Malaysia.

[24] Sayan Kumar Shaw, Arjun Sil, Experimental study on cyclic loading characteristics of fly ash as partial replacement of cement in beam-column joint, Case Studies in Construction Materials, sci,https://doi.org/10.1016/j.cscm.2020.e00362. Volume 13, pp: 1-19, December 2020, e00362.

[25] Avneesh Pandey , Satyaveer Singh, A Comprehensive study of effect of fly-ash admixtures on durability of high performance concrete", Journal of Emerging Technologies and Innovative Research, May 2019, Volume 6, Issue 5, (ISSN-2349-5162),pp-586-588.