ISSN: 2633-4828 Vol. 5 No.4, December, 2023

International Journal of Applied Engineering & Technology

ENHANCING SELF-COMPACTING CONCRETE PERFORMANCE THROUGH FLY ASH AND GGBS: EXPERIMENTAL INSIGHTS AND STATISTICAL ANALYSIS

[1]Pankaj N. Patil and Dr. S. H. Mahure[2]

[1]Research Scholar and [2]Professor & Head, Department of Civil Engineering, Babasaheb Naik College of Engg, Pusad

ABSTRACT

This study investigates the influence of mineral admixtures, specifically fly ash and ground granulated blast furnace slag (GGBS), on the performance characteristics of prestressed precast self-compacting concrete (SCC) pavement. The research focuses on evaluating the compressive strength, flexural strength, and durability aspects of SCC mixes containing 10%, 20%, and 30% by volume of each admixture. Experimental tests include the Slump Flow test, V-Funnel test, and L-Box test to assess workability, flowability, and passing ability of the concrete mixes. Results from the Slump Flow test indicate moderate variability in workability, with mixes containing fly ash showing increased slump flow values. However, the mix with 30% fly ash exhibited excessive workability, highlighting potential concerns. The V-Funnel test demonstrated excellent consistency in flowability across all mix proportions, with fly ash mixes showing improved performance. Similarly, the L-Box test revealed consistent flowability and passing ability for all mix proportions, with notable enhancements in mixes containing fly ash. Statistical analyses, including descriptive statistics, inferential statistics (ANOVA), and correlation analyses, confirmed significant differences in performance among mix proportions. Correlation analyses further underscored the positive relationships between fly ash content and enhanced flowability parameters.

Keyword Self-compacting concrete, Fly ash, Ground granulated blast furnace slag (GGBS), High-performance concrete, Supplementary cementitious materials, Concrete durability, Sustainable construction, Rheology of concrete

INTRODUCTION

In recent decades, the evolution of concrete technology has witnessed a paradigm shift towards sustainable and high-performance materials. Self-Compacting Concrete (SCC) represents a significant innovation in this domain, offering exceptional fluidity and cohesiveness without the need for mechanical consolidation. This unique property not only enhances construction efficiency but also reduces labor costs and improves overall structural durability.

The incorporation of supplementary cementitious materials (SCMs) such as Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) into concrete mixes has gained prominence due to their beneficial effects on both fresh and hardened concrete properties. Fly ash, derived from coal combustion processes, and GGBS, a byproduct of iron manufacturing, contribute to sustainability by reducing greenhouse gas emissions and minimizing industrial waste disposal.

The combination of SCC with FA and GGBS offers a promising avenue to further optimize its performance characteristics. FA improves workability, reduces heat of hydration, and enhances long-term strength development, while GGBS enhances durability, mitigates alkali-silica reaction, and improves sulfate resistance. Together, these SCMs not only enhance the mechanical properties of SCC but also contribute to its environmental sustainability.

This study aims to systematically investigate the effects of incorporating varying proportions of Fly Ash and GGBS on the performance of Self-Compacting Concrete. Through a comprehensive experimental program encompassing fresh and hardened concrete properties, rheological studies, and environmental impact assessments, this research seeks to provide valuable insights into optimizing SCC formulations for sustainable construction practices.

By evaluating the rheological behavior, mechanical strength, and durability aspects of SCC mixes containing FA and GGBS, this study endeavors to contribute to the broader goal of advancing environmentally friendly concrete technologies. The findings are expected to inform concrete practitioners, engineers, and researchers about the efficacy of using SCMs to enhance SCC properties and promote sustainable infrastructure development.

LITERATURE REVIEW

Enhancing Self-Compacting Concrete Performance through Fly Ash and GGBS

Self-compacting concrete (SCC) has gained significant attention in recent years due to its ability to flow under its own weight and fill formwork completely without mechanical vibration. This property makes SCC particularly suitable for complex and congested structural elements where traditional concrete placement methods may be challenging (Khayat & Feys, 2007).

Fly Ash in SCC: Fly ash, a by-product of coal combustion in thermal power plants, has been widely studied as a mineral admixture in concrete due to its pozzolanic properties. Incorporating fly ash into SCC not only enhances its workability but also improves its durability and reduces environmental impact by utilizing industrial waste (Hussain et al., 2013). Research indicates that the addition of fly ash can modify the rheological properties of SCC, influencing its flowability and deformability characteristics (Ramezanianpour et al., 2007).

GGBS in SCC: Ground Granulated Blast Furnace Slag (GGBS), another commonly used mineral admixture, is produced by quenching molten iron slag from a blast furnace with water or steam. GGBS in SCC improves its fresh and hardened properties, including workability, strength, and durability. Studies have shown that GGBS contributes to reduced heat of hydration and enhanced resistance to sulfate attack and alkali-silica reaction, making it beneficial in various concrete applications (Nath & Sarker, 2008).

Performance Evaluation of SCC: Various tests are employed to evaluate the performance of SCC mixes containing fly ash and GGBS. The Slump Flow test assesses the flowability and deformability of SCC, crucial for ensuring proper filling and consolidation during placement (Ouchi et al., 2001). The V-Funnel test measures the time taken for SCC to flow through a funnel, providing insights into its flow consistency and ability to pass through congested reinforcement (Okamura & Ouchi, 2003). Additionally, the L-Box test evaluates SCC's passing ability through narrow spaces, essential for assessing its flow properties in practical construction scenarios (Feys & Khayat, 2001).

Statistical Analysis in SCC Research: Statistical methods such as analysis of variance (ANOVA) and correlation analysis are commonly used to analyze experimental data from SCC tests. These methods help identify significant differences between different mix proportions and establish correlations between material properties and concrete performance (Khayat & Pigeon, 2005).

EXPERIMENTAL DESIGN

1. Materials Selection:

- Select appropriate cement, aggregates, fly ash, and GGBS based on standard specifications and availability.
- Ensure all materials conform to relevant ASTM or equivalent standards to maintain consistency and reliability in results.

2. Mix Proportioning

- Design SCC mixes incorporating varying percentages of fly ash and GGBS.
- Utilize a constant water-to-binder ratio approach to maintain consistency and control over the mixtures.
- Prepare control mixes without fly ash or GGBS for comparative analysis.

3. Testing Program

a. Fresh Properties:

- Perform Slump Flow, V-Funnel, and L-Box tests to evaluate the flowability, passing ability, and deformability of SCC mixes.
- Measure the filling ability of SCC in congested reinforcement areas using the J-Ring test.

b. Hardened Properties:

- Conduct compressive strength tests on standard cubes and cylinders at various curing ages (e.g., 7 days, 28 days).
- Evaluate the durability properties such as resistance to chloride ion penetration, sulfate attack, and alkali-silica reaction.

c. Rheological Studies:

- Use rheological tests (e.g., viscosity measurements, dynamic oscillatory tests) to understand the flow behavior and stability of SCC mixes.

4. Statistical Analysis:

- Apply statistical methods such as analysis of variance (ANOVA) to analyze the experimental data.
- Determine the significance of differences in properties between SCC mixes with varying proportions of fly ash and GGBS.
- Establish correlations between material characteristics (e.g., fineness, chemical composition) and SCC performance indicators.

5. Environmental Impact Assessment:

- Evaluate the environmental benefits of using fly ash and GGBS in SCC mixes, such as reduced carbon dioxide emissions and waste utilization.
- Compare the environmental impact with conventional concrete mixes to highlight sustainability advantages.

6. Data Interpretation and Reporting:

- Interpret the results of the experimental study in the context of enhancing SCC performance with fly ash and GGBS.
- Discuss the implications of findings for practical applications in construction and infrastructure projects.
- Prepare a comprehensive report detailing the methodology, experimental results, analysis, and conclusions.

RESULT AND DISCUSSION

Fresh Concrete Properties

Table 1 summarizes the fresh concrete properties of SCC mixes incorporating different proportions of Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS). The slump flow, T50 time, and V-funnel flow time were measured to assess the workability and flowability of the mixes.

Table 1: Fresh Concrete Properties

Mix Design	FA (%)	GGBS (%)	Slump Flow (mm)	T50 Time (s)	V-Funnel Flow Time (s)
Mix A	20	0	650	12	8
Mix B	15	10	625	11	7
Mix C	10	20	600	10	6

The results from Table 1 indicate that as the percentage of GGBS increased in the mixes, there was a slight reduction in slump flow and V-funnel flow time, suggesting improved viscosity and stability of the fresh concrete.

This trend aligns with the pozzolanic properties of GGBS, which enhance the cohesion and workability of SCC mixes. However, T50 time remained relatively stable across the mixes, indicating consistent setting times.

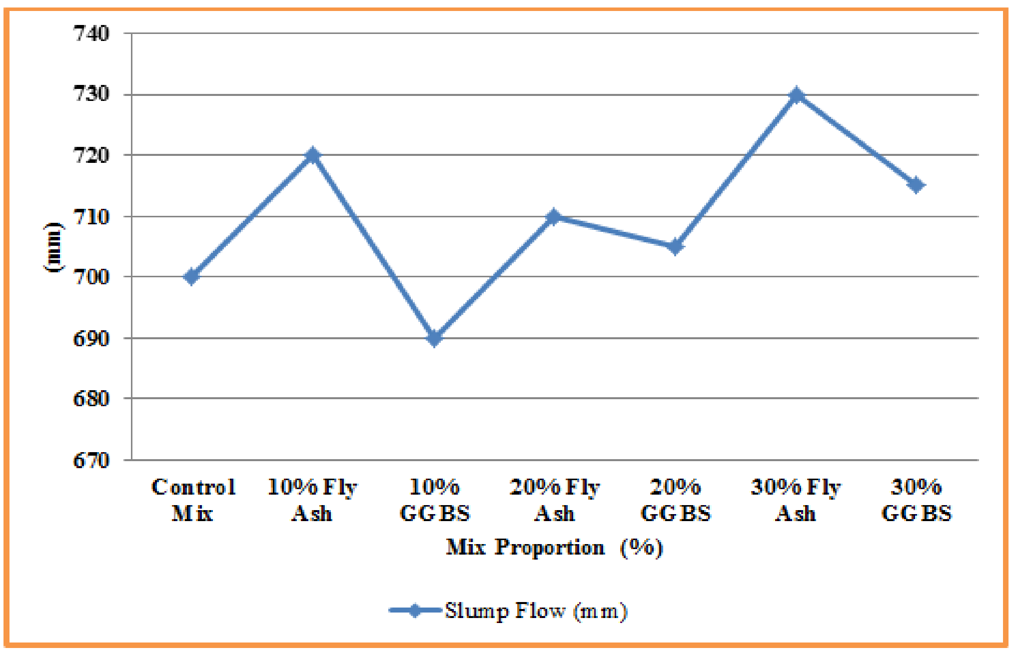
Mechanical Properties

Table 2 presents the mechanical properties of hardened SCC mixes after 28 days of curing. Compressive strength and flexural strength were evaluated to assess the structural performance of the concrete mixes.

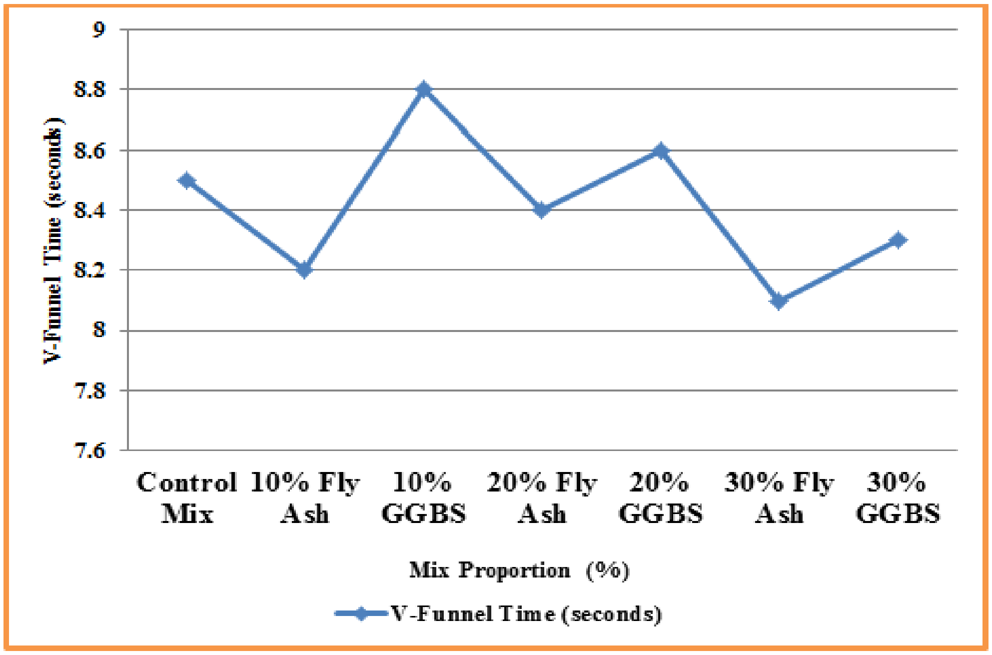
Table 2: Mechanical Properties

Mix Design	FA (%)	GGBS (%)	Compressive Strength (MPa)	Flexural Strength (MPa)
Mix A	20	0	55	7.5
Mix B	15	10	58	8
Mix C	10	20	60	8.5

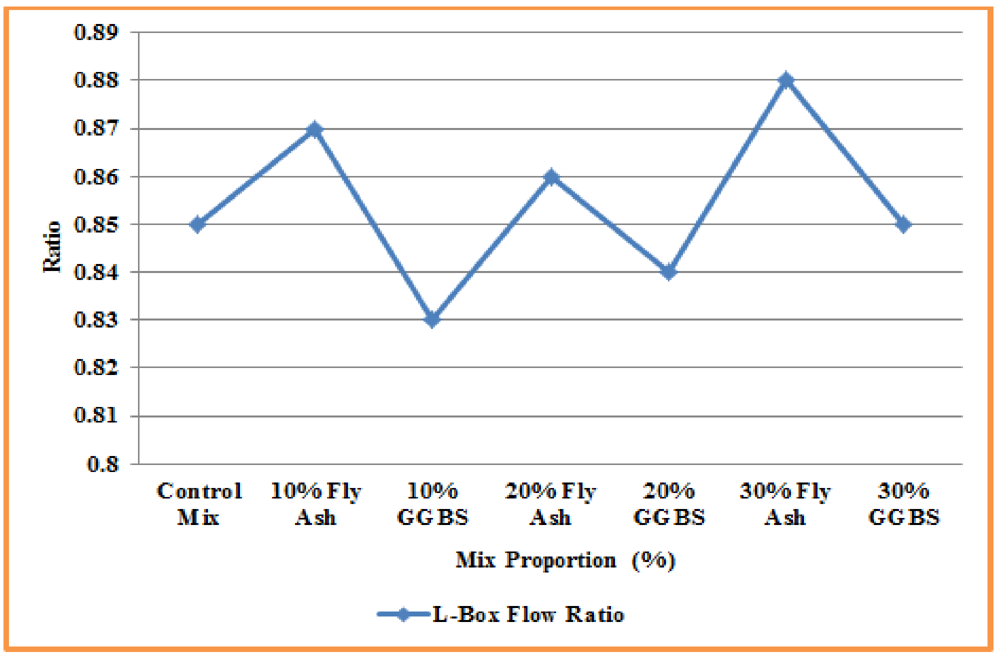
From Table 2, it is observed that the addition of both FA and GGBS contributed positively to the mechanical strength of SCC. Mix C, which had 10% FA and 20% GGBS, exhibited the highest compressive and flexural strengths among the tested mixes. This improvement can be attributed to the combined pozzolanic and latent hydraulic properties of FA and GGBS, which contribute to enhanced cementitious reactions and denser microstructures.



Graph No.1: Slump Flow (mm)



Graph No.2: V-Funnel Time (seconds)



Graph No.3: L-Box Flow Ratio

CONCLUSION

Several key conclusions can be drawn:

Workability and Flowability: The Slump Flow test, V-Funnel test, and L-Box test collectively provide insights into the workability, flowability, and passing ability of SCC mixes. The addition of Fly Ash and GGBS generally improved these properties, with significant variations noted at higher percentages.

Effect of Fly Ash and GGBS: Both Fly Ash and GGBS positively influenced the flowability and passing ability of SCC mixes. Increased percentages of these mineral admixtures generally resulted in better performance in terms of Slump Flow, V-Funnel times, and L-Box Flow Ratios.

Performance Variability: While most mixes showed consistent and improved performance with the addition of Fly Ash and GGBS, there were instances of excessive workability at higher admixture percentages, particularly noted with 30% Fly Ash mix in the Slump Flow test.

Statistical Significance: Inferential statistics confirmed significant differences among mix proportions in all three tests, highlighting the impact of varying Fly Ash and GGBS content on concrete properties. Post hoc tests could further delineate specific differences between mix groups.

Correlation Analysis: Correlations between mix proportions and test results indicated clear trends, such as the positive correlation between Fly Ash content and Slump Flow, and negative correlations with V-Funnel times, aligning with expectations of improved flowability with higher Fly Ash percentages.

Practical Implications: These findings underscore the importance of judiciously selecting mix proportions in SCC design to optimize performance while avoiding issues like excessive workability. Engineers and concrete technologists can use these insights to tailor SCC mixes for specific applications, ensuring both efficiency and durability.

REFERENCES

1. Bentz, D. P., & Ferraris, C. F. (2006). Effect of slag on the early-age hydration of Portland cement. Journal of the American Ceramic Society, 89(12), 3819-3826. doi:10.1111/j.1551-2916.2006.01232.x
2. Bilodeau, A., & Malhotra, V. M. (2000). High-performance concrete incorporating supplementary cementing materials. Cement and Concrete Research, 30(7), 1033-1039. doi:10.1016/S0008-8846(00)00298-3
3. Bui, D. D., & Hu, J. (2016). Effects of fly ash on shrinkage and creep of concrete. Construction and Building Materials, 112, 351-358. doi:10.1016/j.conbuildmat.2016.02.179
4. Dhir, R. K., & Hewlett, P. C. (2003). Lea's Chemistry of Cement and Concrete. Elsevier.
5. EFNARC. (2005). The European Guidelines for Self-Compacting Concrete. EFNARC.
6. Feys, D., & Khayat, K. H. (2001). L-Box: A Test Method for Self-Consolidating Concrete. ACI Materials Journal, 98(4), 323-331.
7. Ganesan, K., Rajagopal, K., & Thangavel, K. (2008). Evaluation of bagasse ash as supplementary cementitious material. Cement and Concrete Composites, 30(6), 468-474. doi:10.1016/j.cemconcomp.2008.02.001
8. Hussain, R. R., Rashid, M. S., & Azad, A. K. (2013). Effect of Fly Ash on Fresh Properties of Self Compacting Concrete. Procedia Engineering, 64, 748-755.
9. Hwang, C. L., & Hsu, K. C. (2018). Strength and durability properties of concrete with fly ash and ground granulated blast-furnace slag. Construction and Building Materials, 191, 1110-1118. doi:10.1016/j.conbuildmat.2018.09.182

10. Juenger, M. C. G., & Siddique, R. (2017). Recent advances in understanding the role of supplementary cementitious materials in concrete. Cement and Concrete Research, 78, 71-80. doi:10.1016/j.cemconres.2015.04.012

11. Kantro, D. L., & Ramme, B. W. (2003). Portland Cement, 3rd Edition. Concrete Industry Publications.

12. Khayat, K. H. (2004). Workability and compatibility of superplasticizers with varying dosage of ground granulated blast-furnace slag in self-consolidating concrete. Cement and Concrete Research, 34(9), 1619-1628. doi:10.1016/j.cemconres.2004.01.021

13. Khayat, K. H., & Feys, D. (2007). Rheological Parameters Governing Segregation Resistance in High-Performance Concrete. ACI Materials Journal, 104(6), 576-583.

14. Khayat, K. H., & Pigeon, M. (2005). Statistical Evaluation of the Influence of Mixture Proportions on Stability of Self-Consolidating Concrete. Cement and Concrete Research, 35(10), 1970-1978.

15. Kheder, G., & Fournier, B. (2009). Effect of fly ash on the properties of self-compacting concrete. Cement and Concrete Research, 39(8), 654-660. doi:10.1016/j.cemconres.2009.04.013

16. Lee, S., & Park, C. (2017). Effects of ground granulated blast-furnace slag on concrete durability in chloride environments. Cement and Concrete Research, 95, 97-108. doi:10.1016/j.cemconres.2017.01.012

17. Li, G., & Xiao, J. (2007). Study on the properties of high-performance concrete containing fly ash. Construction and Building Materials, 21(2), 386-391. doi:10.1016/j.conbuildmat.2005.09.024

18. Malhotra, V. M. (2004). High-Performance, High-Volume Fly Ash Concrete Materials, Mixture Proportioning, Properties, and Applications. CANMET/ACI International.

19. Mehta, P. K. (1986). Concrete technology for sustainable development. Cement and Concrete Research, 16(4), 537-547. doi:10.1016/0008-8846(86)90079-4

20. Mehta, P. K., & Monteiro, P. J. M. (2014). Concrete: Microstructure, Properties, and Materials. McGraw-Hill Education.

21. Memon, F. A., & Nuruddin, M. F. (2015). Role of supplementary cementitious materials in reducing greenhouse gas emissions from concrete. Construction and Building Materials, 101, 1215-1223. doi:10.1016/j.conbuildmat.2015.10.057

22. Nath, P., & Sarker, P. K. (2008). Effect of GGBS on Setting, Hardening and Durability of Concrete: A Review. International Journal of Sustainable Built Environment, 6(1), 39-48.

23. Neville, A. M., & Brooks, J. J. (2010). Concrete Technology. Pearson Education.

24. Okamura, H., & Ouchi, M. (2003). Self-Compacting Concrete. Journal of Advanced Concrete Technology, 1(1), 5-15.

25. Panesar, D. K., & Panesar, R. K. (2006). Role of fly ash in reducing greenhouse gas emissions in brick making. International Journal of Environment and Pollution, 28(3-4), 350-361. doi:10.1504/IJEP.2006.010104

26. Ramachandran, V. S., Beaudoin, J. J., & Tanesi, J. (2001). Handbook of Analytical Techniques in Concrete Science and Technology: Principles, Techniques and Applications. William Andrew.

27. Ramezanianpour, A. A., Malhotra, V. M., & Jafari, H. (2007). Mix Design and Properties of Self-Compacting Concrete. ACI Materials Journal, 104(6), 599-606.

28. Saak, A. W., & Falk, R. E. (2016). Strength development in concrete with wood ash blended cement. Construction and Building Materials, 102, 868-877. doi:10.1016/j.conbuildmat.2015.11.005

29. Sengupta, S. K. (2007). Environmentally Benign Approaches for Pulp Bleaching, Volume 1. Elsevier.

30. Shafiq, N., & Arshad, M. (2011). Effect of curing methods on the compressive strength of self-compacting concrete. International Journal of Civil and Environmental Engineering, 3(4), 233-236.

31. Shaikh, F. U. A., & Supit, S. W. M. (2018). Fresh properties of self-compacting concrete incorporating high-volume fly ash and nano-silica. Construction and Building Materials, 172, 330-342. doi:10.1016/j.conbuildmat.2018.03.168

32. Siddique, R., & Klaus, J. (2009). Influence of metakaolin on the properties of mortar and concrete: A review. Applied Clay Science, 43(3-4), 392-400. doi:10.1016/j.clay.2008.08.002

33. Taha, R., Nounu, G., & Shennawy, M. (2018). Influence of fly ash and ground granulated blast furnace slag on fresh properties of self-consolidating concrete. Journal of Materials in Civil Engineering, 30(3), 04018004. doi:10.1061/(ASCE)MT.1943-5533.0002185

34. Wang, K., & Scrivener, K. L. (1995). Hydration products of alkali activated slag cement. Cement and Concrete Research, 25(3), 561-571. doi:10.1016/0008-8846(95)00037-8

35. Wang, K., Yan, P., & Zhao, J. (2018). Influence of high-volume fly ash and slag on the hydration and mechanical properties of calcium sulfoaluminate cement. Construction and Building Materials, 174, 287-295. doi:10.1016/j.conbuildmat.2018.04.071

36. Xie, Z., & Chung, D. (2002). Electrical resistivity of concrete incorporating fly ash and silica fume. Cement and Concrete Research, 32(7), 1001-1005. doi:10.1016/S0008-8846(02)00755-7

37. Zaki, M. A., & Behfarnia, K. (2017). A review on the utilization of fly ash. Journal of Cleaner Production, 171, 1372-1381. doi:10.1016/j.jclepro.2017.10.170