IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, June 2026
Impact Factor: 8.2

Review of Hybrid Admixture Systems on the Strength and Durability Characteristics of Self-Compacting Concrete

Patil Shivshankar Sakharam[1] and Dr. Manoj Sharma[2]
[1]Research Scholar, Department of Civil Engineering
[2]Associate Professor, Department of Civil Engineering
Vikrant University Gwalior M.P

Abstract: *Self-Compacting Concrete (SCC) is an advanced concrete technology capable of flowing, passing through congested reinforcement, and filling formwork without the need for external vibration. Its performance depends strongly on the interaction between cementitious materials, aggregates, water, and chemical admixtures. In recent years, hybrid admixture systems combining different chemical admixtures, mineral admixtures, supplementary cementitious materials, and fine pozzolanic or industrial by-products have received considerable attention because a single admixture may not simultaneously provide adequate workability, strength development, and long-term durability. This review examines the influence of hybrid admixture systems on the fresh, mechanical, and durability characteristics of SCC. Particular attention is given to combinations involving superplasticizers, viscosity-modifying agents, fly ash, silica fume, ground granulated blast-furnace slag, metakaolin, rice husk ash, and other supplementary cementitious materials.*

The review indicates that appropriately proportioned hybrid systems can improve flowability, segregation resistance, compressive strength, tensile strength, permeability resistance, and resistance to aggressive environmental conditions. Superplasticizers primarily enhance flowability by reducing water demand, whereas viscosity-modifying admixtures improve stability and resistance to segregation. Mineral admixtures can refine the pore structure and contribute to later-age strength through pozzolanic or latent hydraulic reactions.

Keywords: Self-Compacting Concrete, Supplementary Cementitious Materials, Strength, Durability, Workability, Permeability, Sustainable Concrete

I. INTRODUCTION

Self-Compacting Concrete (SCC) represents an important development in concrete technology because it can flow and consolidate under its own weight without mechanical vibration. The technology is particularly useful in heavily reinforced structural members, complicated formwork, precast components, tunnel structures, bridges, columns, and other applications where conventional vibration is difficult or undesirable. The principal requirements of SCC are high filling ability, adequate passing ability, and resistance to segregation. These requirements must be achieved while maintaining the desired mechanical strength and durability.

The development of SCC has been closely associated with the use of high-range water-reducing admixtures, commonly known as superplasticizers. These admixtures allow substantial reduction in mixing water while maintaining high fluidity. However, increasing fluidity may also increase the possibility of segregation and bleeding. Therefore, viscosity-modifying admixtures and suitable mineral additions are frequently incorporated to control the rheological behaviour of the concrete.

DOI: 10.48175/568

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, June 2026
Impact Factor: 8.2

A hybrid admixture system refers broadly to the combined use of two or more complementary admixture or cementitious components designed to obtain a performance level that is difficult to achieve through a single component. Such systems may combine chemical admixtures with mineral admixtures or multiple chemical admixtures with different functions. For example, a superplasticizer can provide high flowability while a viscosity-modifying agent can improve stability. Similarly, the combination of silica fume and fly ash can provide complementary effects on early and later-age properties. The performance of SCC is therefore governed by a complex interaction among water-to-binder ratio, powder content, aggregate grading, admixture dosage, cement characteristics, supplementary cementitious materials, curing conditions, and environmental exposure. A suitable hybrid system can enhance the overall performance of SCC, whereas an inappropriate combination can result in excessive viscosity, loss of workability, delayed setting, poor strength development, or admixture incompatibility.

Table 1. Major Components Used in Hybrid SCC Admixture Systems

Component	Primary Function	Expected Effect on SCC
Superplasticizer	Water reduction and dispersion	Improves flowability and reduces water demand
Viscosity-modifying admixture	Rheological control	Reduces segregation and bleeding
Fly ash	Mineral replacement	Improves workability and later-age durability
Silica fume	Highly reactive pozzolan	Increases density and strength
GGBS	Supplementary cementitious material	Improves later-age strength and durability
Metakaolin	Reactive pozzolan	Improves strength and pore refinement
Rice husk ash	Siliceous pozzolan	Can improve strength and permeability resistance
Limestone powder	Filler material	Improves particle packing and fresh stability

HYBRID ADMIXTURE SYSTEMS IN SELF-COMPACTING CONCRETE

The concept of hybrid admixture systems is based on combining materials having different but complementary functions. In SCC, achieving high flowability alone is insufficient because excessive fluidity may result in segregation and bleeding. Conversely, excessive viscosity can reduce filling ability and increase pumping resistance. Hybridization is therefore intended to establish an appropriate balance between fluidity and stability.

The most common chemical hybrid system involves a high-range water-reducing admixture combined with a viscosity-modifying admixture. The superplasticizer disperses cement particles and permits the concrete to flow at a relatively low water-to-binder ratio. The viscosity-modifying component increases cohesion and controls the movement of solid particles within the paste. The combined effect can produce a mixture that flows easily while maintaining homogeneity.

Another important hybrid approach involves combining different supplementary cementitious materials. Fly ash generally improves fresh flow because of its particle characteristics, while silica fume provides very fine particles and high pozzolanic reactivity. Their combined use can produce a more refined pore structure while maintaining satisfactory workability when the chemical admixture dosage is properly adjusted.

GGBS can also be combined with fly ash, silica fume, or metakaolin. Such combinations modify hydration kinetics and pore structure and can improve resistance to chloride penetration, sulfate attack, and other durability-related mechanisms. However, the response is dependent on replacement percentage and curing conditions.

Table 2. Typical Hybrid Admixture Combinations and Their Functions

Hybrid System	Main Objective	Major Advantage	Possible Limitation
Superplasticizer + VMA	Flowability + stability	Good filling ability and segregation resistance	Excessive viscosity
Superplasticizer + Fly ash	Flow + workability	Improved fresh properties	Slower early strength

ISSN 2581-9429 IJARSCT

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, June 2026
Impact Factor: 8.2

Superplasticizer + Silica fume	Flow + high strength	Dense microstructure	Higher water/admixture demand
Fly ash + Silica fume	Balanced mineral modification	Improved long-term performance	Mixture optimization required
GGBS + Fly ash	Durability + sustainability	Reduced permeability	Slower early strength
Silica fume + GGBS	Strength + durability	Dense pore structure	Increased paste viscosity
Metakaolin + Superplasticizer	Strength + flow	High reactivity and strength	Higher admixture requirement
Rice husk ash + Superplasticizer	Sustainability + performance	Utilization of agricultural waste	Material variability

The effectiveness of a hybrid system is determined not simply by adding more admixtures but by understanding the interaction among their physical and chemical characteristics. Compatibility between cement and chemical admixtures is particularly important. Cement composition, fineness, alkali content, sulfate balance, and temperature can influence admixture performance.

INFLUENCE ON FRESH AND MECHANICAL PROPERTIES

Fresh properties are fundamental to the successful production of SCC. The principal fresh-state parameters include slump flow, T500 time, V-funnel flow time, L-box ratio, J-ring passing ability, and resistance to segregation. Hybrid admixture systems can significantly modify these parameters.

Superplasticizers generally increase slump flow by dispersing cement particles and reducing interparticle attraction. The resulting mixture can attain high fluidity without increasing the mixing water. However, when the dosage becomes excessive, the mixture may become unstable. The incorporation of a viscosity-modifying admixture can compensate for this problem by increasing cohesion.

Mineral admixtures also influence fresh properties. Fly ash can improve flowability because its particles may have a relatively smooth morphology and can improve particle packing. Silica fume, in contrast, has extremely fine particles and a large specific surface area, which can increase water demand and viscosity. Consequently, the use of silica fume normally requires careful adjustment of the superplasticizer dosage.

Mechanical strength is another major performance parameter. Compressive strength depends on the water-to-binder ratio, cement hydration, pozzolanic reactions, particle packing, curing, and pore structure. Hybrid systems containing reactive mineral additions can enhance later-age strength through secondary hydration and pore refinement.

Silica fume and metakaolin can contribute substantially to strength development because of their high pozzolanic activity. Fly ash may provide slower strength development but can contribute to later-age strength and durability. GGBS can similarly contribute to long-term strength while reducing the amount of Portland cement required.

Table 3. General Influence of Hybrid Systems on Fresh and Mechanical Properties

Property	Superplasticizer	VMA	Fly Ash	Silica Fume	GGBS
Slump flow	↑↑	↓/→	↑	↓/→	→/↑
Segregation resistance	→	↑↑	↑	↑	↑
Passing ability	↑	→/↓	↑	→/↓	→
Early compressive strength	↑	→	↓/→	↑	↓/→
Later-age strength	↑	→	↑	↑↑	↑
Cohesion	→	↑↑	↑	↑↑	↑
Water demand	↓	→/↑	↓/→	↑↑	→
Pumpability	↑	→/↓	↑	↓/→	→

Note: ↑ = improvement, ↓ = reduction, → = generally limited or dependent on mixture proportioning.

The tensile and flexural strengths of SCC are also influenced by hybrid admixtures. Improved particle packing and reduced internal voids can increase resistance to cracking and tensile stresses. Nevertheless, the relationship is not linear because excessive fine materials can increase shrinkage and alter the cracking behaviour of concrete.

INFLUENCE ON DURABILITY CHARACTERISTICS

Durability is one of the most important reasons for incorporating mineral admixtures and hybrid systems into SCC. Concrete durability is strongly influenced by pore structure, permeability, moisture transport, chemical reactions, cracking, and exposure conditions. A dense and well-connected microstructure generally reduces the penetration of harmful substances.

Hybrid admixture systems can improve durability by reducing capillary porosity and increasing the compactness of the cementitious matrix. Silica fume is particularly effective in refining pores because its very fine particles fill voids and its pozzolanic reaction produces additional hydration products. Fly ash and GGBS can also contribute to microstructural refinement, particularly at later ages.

Resistance to chloride penetration is a major concern for reinforced concrete structures. Chloride ions can reach reinforcement through interconnected pores and initiate corrosion. Hybrid systems incorporating silica fume, GGBS, or fly ash can reduce chloride transport by refining the pore network and modifying the chemical binding characteristics of the cementitious system.

Sulfate resistance can also be improved by appropriate use of supplementary cementitious materials. GGBS and fly ash can reduce the susceptibility of concrete to certain sulfate-related deterioration mechanisms. However, the actual performance depends on the type and concentration of sulfate, cement composition, curing, temperature, and exposure duration.

Water absorption and sorptivity are useful indicators of the permeability-related behaviour of concrete. Properly designed hybrid SCC generally exhibits lower water absorption because of its refined pore structure. Nevertheless, excessive use of highly reactive fine materials may increase autogenous shrinkage or alter cracking behaviour.

Table 4. Durability Effects of Selected Hybrid Systems

Durability Parameter	Fly Ash-Based System	Silica Fume-Based System	GGBS-Based System	Combined System
Water absorption	Reduced	Strongly reduced	Reduced	Generally reduced
Chloride penetration	Reduced	Strongly reduced	Strongly reduced	Very low when optimized
Sulfate resistance	Improved	Improved	Strongly improved	Improved to strongly improved
Permeability	Reduced	Strongly reduced	Reduced	Strongly reduced
Pore refinement	Moderate	High	Moderate–high	High
Carbonation resistance	Variable	Generally improved	Variable	Depends on proportioning
Long-term strength	Improved	Strongly improved	Strongly improved	Strongly improved
Resistance to aggressive exposure	Improved	Improved	Strongly improved	Potentially high

The durability performance of hybrid SCC should therefore be evaluated under realistic exposure conditions rather than based only on compressive strength. Long-term testing is particularly important because different mineral admixtures exhibit different hydration rates and microstructural development.

OPTIMIZATION, SUSTAINABILITY AND PRACTICAL CONSIDERATIONS

The design of a hybrid admixture system requires optimization rather than simply increasing the quantity of individual components. The optimum dosage depends on cement characteristics, aggregate grading, water-to-binder ratio, powder volume, desired flowability, curing conditions, and environmental exposure.

One major challenge is chemical compatibility. A superplasticizer that performs effectively with one cement may produce a different response with another cement. Similarly, the combination of superplasticizers and viscosity modifiers can produce excessive viscosity if dosages are not properly controlled. Trial mixtures are therefore essential for establishing optimum proportions.

Another consideration is the balance between early and later-age strength. Systems containing substantial quantities of fly ash or GGBS may show slower early strength development but provide significant long-term benefits. In contrast, silica fume and metakaolin can promote rapid strength development but may increase viscosity and water demand.

Hybrid admixture systems also have an important sustainability dimension. Partial replacement of Portland cement with fly ash, GGBS, rice husk ash, and other supplementary materials can reduce cement consumption and potentially lower the environmental impact associated with concrete production. The utilization of industrial and agricultural by-products can also contribute to waste reduction.

However, sustainability should not be assessed only on the basis of cement replacement. Transportation distance, processing requirements, availability, durability improvement, service life, and material consistency should also be considered. A durable concrete structure with a longer service life can provide environmental benefits by reducing repair and replacement requirements.

Table 5. Key Parameters for Optimizing Hybrid SCC

Parameter	Low/Insufficient Level	Optimum Condition	Excessive Level
Superplasticizer	Poor flow	High flow with stability	Segregation/workability instability
VMA	Poor cohesion	Controlled viscosity	Excessive viscosity
Silica fume	Limited pore refinement	Dense microstructure	High water demand
Fly ash	Limited replacement benefit	Improved workability and durability	Slow early strength
GGBS	Limited durability contribution	Good long-term performance	Delayed early strength
Water-to-binder ratio	High permeability	Controlled permeability and workability	Excessive water demand
Powder content	Poor filling ability	Adequate stability	Excessive viscosity
Curing	Poor hydration	Proper strength and durability development	—

From a practical perspective, SCC produced using a hybrid system should undergo systematic fresh-state testing before large-scale application. Slump flow alone is not sufficient to establish SCC quality. Passing ability, segregation resistance, viscosity, setting behaviour, strength development, and durability indicators should also be evaluated.

Future research should focus on multifunctional hybrid systems, low-carbon binders, recycled materials, nano-modified admixtures, self-healing components, and performance-based mixture design. Advanced characterization techniques can further clarify the relationship between admixture interactions, hydration products, pore structure, and long-term durability.

II. CONCLUSIONS AND REVIEW-BASED RESEARCH GAPS

The review demonstrates that hybrid admixture systems provide an effective strategy for improving the overall performance of Self-Compacting Concrete. The combination of high-range water reducers with viscosity-modifying

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, June 2026
Impact Factor: 8.2

agents can provide a suitable balance between flowability and stability. The incorporation of supplementary cementitious materials such as fly ash, silica fume, GGBS, metakaolin, and rice husk ash can further modify the fresh, mechanical, and durability characteristics of SCC.

The major conclusions of the review are:

Hybrid admixture systems can provide better control of SCC fresh properties than single-admixture systems when properly proportioned.

Superplasticizers are essential for achieving high flowability at reduced water content.

Viscosity-modifying admixtures can improve cohesion and reduce segregation and bleeding.

Silica fume and metakaolin can substantially improve strength and pore refinement but may increase viscosity and admixture demand.

Fly ash and GGBS can improve later-age strength, permeability resistance, and durability while reducing Portland cement consumption.

Properly designed hybrid systems can reduce water absorption and chloride penetration and improve resistance to aggressive environments.

Excessive admixture or mineral replacement can negatively affect workability, setting, early strength, and shrinkage behaviour.

Cement–admixture compatibility is a critical factor governing the effectiveness of hybrid systems.

The optimum hybrid combination must be established according to the required structural performance and exposure environment.

Hybrid admixture technology has significant potential for developing durable, high-performance, and more sustainable SCC.

Despite considerable progress, several research gaps remain. There is a need for standardized approaches for evaluating complex hybrid admixture interactions, particularly when several supplementary cementitious materials are used simultaneously. Long-term field investigations are also required to validate laboratory durability results. Further research should examine the effects of hybrid systems under combined exposure conditions involving chloride, sulfate, carbonation, freeze–thaw action, elevated temperature, and cyclic wetting and drying.

Another important research area is the development of low-carbon SCC using locally available industrial and agricultural by-products. The interaction between novel chemical admixtures and alternative binders also requires systematic investigation. Future studies should integrate fresh-property optimization, mechanical performance, durability, life-cycle considerations, and economic assessment into a unified mixture-design framework.

Overall, hybrid admixture systems should not be considered merely as a method for increasing concrete strength. Their greater significance lies in their ability to simultaneously control workability, stability, strength, permeability, durability, and sustainability. With appropriate material selection and optimization, hybrid admixture systems can contribute significantly to the wider application of SCC in modern and durable concrete construction.

REFERENCES

1. Domone, P. L. (2007). A review of the hardened mechanical properties of self-compacting concrete. *Cement and Concrete Composites, 29*(1), 1–12.
2. Dinakar, P., Babu, K. G., & Santhanam, M. (2008). Durability properties of high volume fly ash self-compacting concretes. *Cement and Concrete Composites, 30*(10), 880–886.
3. Khayat, K. H., & Guizani, Z. (1997). Use of viscosity-modifying admixture to reduce top-bar effect of anchored bars cast with fluid concrete. *ACI Materials Journal, 94*(4), 332–341.
4. Khayat, K. H., & Roussel, Y. (2000). Testing and performance of self-consolidating concrete. *ACI Materials Journal, 97*(1), 37–45.
5. Rixom, R., & Mailvaganam, N. (2002). *Chemical admixtures for concrete* (3rd ed.). E & FN Spon.

6. Bui, V. K., Montgomery, D., Hinczak, I., & Turner, K. (2002). Rapid testing method for segregation resistance of self-compacting concrete. *Cement and Concrete Research, 32*(1), 71–78.
7. Assié, S., Escadeillas, G., & Waller, V. (2007). Estimates of self-compacting concrete 'potential' durability. *Construction and Building Materials, 21*(9), 1909–1917.
8. El-Chabib, H., & Syed, A. (2013). Properties of self-consolidating concrete made with high volumes of supplementary cementitious materials. *Journal of Materials in Civil Engineering, 25*(11), 1852–1860.
9. Karthik, H. B., Rao, H. S., & Narasimhan, M. C. (2021). Characteristic assessment of self-compacting concrete with supplementary cementitious materials. *Construction and Building Materials, 297*, 123845.
10. Rols, S., Ambroise, J., Péra, J., & Bournazel, J. P. (1999). Effects of different viscosity agents on the properties of self-leveling concrete. *Cement and Concrete Research, 29*(2), 261–266.
11. Sonebi, M. (2004). Medium strength self-compacting concrete containing fly ash: Modelling using factorial experimental plans. *Cement and Concrete Research, 34*(7), 1199–1208.
12. Kuder, K. G., & Shah, S. P. (2010). Processing of self-consolidating concrete. *ACI Materials Journal, 107*(1), 55–61.
13. Niknezhad, D., Kamali-Bernard, S., & Mesbah, H. A. (2017). Self-compacting concretes with supplementary cementitious materials: Shrinkage and cracking tendency. *Journal of Materials in Civil Engineering, 29*(7).
14. Niknezhad, D., Kamali-Bernard, S., & Brossault, J. Y. (2016). Experimental study of transport properties and natural carbonation of self-compacting concrete incorporating supplementary cementitious materials. *Academic Journal of Civil Engineering, 34*(1), 766–773.
15. Lachemi, M., Hossain, K. M. A., Lambros, V., Nkinamubanzi, P. C., & Bouzoubaa, N. (2004). Self-consolidating concrete incorporating new viscosity modifying admixtures. *Cement and Concrete Research, 34*(6), 917–926.
16. Liu, X., & Yan, J. (2022). Review on the application of supplementary cementitious materials in self-compacting concrete. *Crystals, 12*(2), 180.
17. Sonebi, M., & Bartos, P. J. M. (2000). Hardened SCC and its bond with reinforcement. *Cement and Concrete Composites, 22*(2), 97–104.
18. Dinakar, P., Kali, S., & Rao, M. (2020). Mechanical and durability properties of sustainable self-compacting concrete with recycled concrete aggregate and fly ash, slag and silica fume. *Construction and Building Materials, 231*, 117115.