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Review of Combined Superplasticizer and Viscosity-Modifying Admixtures on the Strength and Durability of Self-Compacting Concrete

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Abstract: *Self-Compacting Concrete is a highly flowable concrete capable of filling formwork and passing through congested reinforcement without mechanical vibration. Its successful production requires an appropriate balance between flowability, passing ability, segregation resistance and stability. Superplasticizers (SPs), particularly modern polycarboxylate-ether-based admixtures, are primarily used to increase flowability by dispersing cement and supplementary cementitious material particles and reducing the water demand.*
However, excessive fluidity may increase the risk of bleeding, segregation and instability. Viscosity-Modifying Admixtures are therefore incorporated to increase cohesion and plastic viscosity, control segregation and improve robustness against variations in water content and aggregate characteristics. The combined use of SP and VMA provides a means of independently controlling the flow and stability of SCC. This review examines the mechanisms of SP and VMA action, their interaction in fresh concrete, and their influence on compressive strength, tensile strength, permeability, chloride resistance, shrinkage and overall durability.

Keywords: Self-Compacting Concrete, Superplasticizer, Viscosity-Modifying Admixture, Compressive Strength, Segregation Resistance, Workability

I. INTRODUCTION

Self-Compacting Concrete has become an important development in modern concrete technology because it can flow under its own weight and fill complex formwork without conventional vibration. The technology is particularly useful in heavily reinforced structural members, thin sections, precast elements and locations where conventional compaction is difficult. European SCC guidance identifies fresh-concrete characteristics such as filling ability, passing ability and resistance to segregation as fundamental requirements for successful SCC production. EFNARC also recognizes powder-type, viscosity-agent-type and combination-type SCC, with the combination approach using both VMA and an appropriate dosage of superplasticizer to control rheology.

The principal challenge in SCC mixture design is obtaining high flowability without compromising stability. Superplasticizers reduce interparticle attraction and disperse cement particles, thereby reducing yield stress and increasing flowability. However, a substantial reduction in yield stress can result in inadequate cohesion if the mixture does not contain sufficient fines or viscosity. VMA can compensate for this problem by increasing the viscosity of the liquid phase and improving suspension of solid particles. Research on VMA has demonstrated that the combined use of suitable VMA and SP dosages can produce mixtures that are simultaneously highly fluid and sufficiently cohesive.

The interaction between these two admixture systems is therefore more important than considering either admixture independently. The SP controls the ease with which concrete flows, whereas VMA primarily controls resistance to segregation and bleeding. Their combined application allows SCC to maintain an appropriate rheological balance.

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Current research continues to investigate this interaction because the optimum combination varies with cement chemistry, aggregate grading, supplementary cementitious materials, water-to-binder ratio, temperature and admixture compatibility.

ROLE OF SUPERPLASTICIZERS IN SCC

Superplasticizers are high-range water-reducing admixtures used to obtain high workability without increasing the water content. Modern polycarboxylate ether superplasticizers are particularly important in SCC because their molecular structure provides effective dispersion of cement particles.

When SP is added to cement paste, adsorption of the admixture on cement particles produces electrostatic and steric repulsion. The particles become more effectively dispersed, reducing flocculation and releasing water previously trapped within particle clusters. Consequently, the concrete develops lower yield stress and greater flowability.

The main advantages of SP in SCC include:

Increased slump-flow diameter.

Reduced water requirement.

Improved filling ability.

Enhanced passing ability.

Improved workability at relatively low water-to-binder ratios.

Potential improvement in compressive strength through water reduction.

However, increasing SP dosage indefinitely is not beneficial. Beyond an optimum dosage, additional SP may provide limited improvement in flow while increasing the possibility of segregation or bleeding. Compatibility between the SP and cement is also important because adsorption behavior depends on cement composition, alkali content, sulfate balance and supplementary materials.

ROLE OF VISCOSITY-MODIFYING ADMIXTURES

VMAs are generally water-soluble polymers or other viscosity-enhancing materials that modify the rheological characteristics of cementitious mixtures. They increase cohesion and plastic viscosity and help keep aggregate particles and cementitious materials uniformly suspended.

EFNARC guidance identifies several benefits of VMA in SCC, including reduced sensitivity to aggregate-moisture variations, improved robustness, reduced segregation and bleeding, and the possibility of obtaining fluid mixtures with lower powder contents.

The action of VMA can involve increased viscosity of the aqueous phase, polymer-chain entanglement, particle bridging and interactions with the ionic environment of cement paste. Recent research emphasizes that VMA performance depends not only on dosage but also on molecular mass, functional groups, charge characteristics, binder chemistry and pore-solution conditions.

Excessive VMA, however, may make SCC too cohesive and viscous. This can reduce slump flow, increase V-funnel time and slow the placement process. EFNARC specifically notes that excessive VMA can produce overly cohesive concrete, with adjustment of superplasticizer sometimes necessary to restore flowability.

SYNERGISTIC ACTION OF SP AND VMA

The combined SP–VMA system can be considered a two-component rheological control mechanism. SP reduces yield stress and increases deformability, while VMA increases plastic viscosity and stability.

Property	Superplasticizer	VMA	Combined Effect
Yield stress	Decreases	May increase slightly	Balanced
Plastic viscosity	Generally decreases	Increases	Controlled viscosity
Flowability	Strongly increases	May decrease	High but controlled
Segregation resistance	May reduce at excessive dosage	Increases	Improved stability

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Bleeding resistance	Limited	Increases	Reduced bleeding
Passing ability	Improves	Can restrict if excessive	Optimized
Robustness	Moderate	High	High
Water demand	Reduces	Usually little direct effect	Low water demand
Surface quality	Improves through filling	Improves stability	Generally improved

The objective is therefore not to maximize either admixture independently but to identify an optimum combination. Early research on VMA systems showed that combinations of VMA and SP could produce highly fluid cement pastes while maintaining sufficient cohesion and water retention.

EFFECT ON FRESH PROPERTIES

Fresh properties are the first indicators of successful SP–VMA interaction. The major SCC tests include slump-flow, T50 time, V-funnel, L-box and segregation-resistance tests.

Table 2. Influence of SP and VMA on Fresh SCC Properties

Fresh Property	Increasing SP	Increasing VMA	Optimum Combined Response
Slump flow	Increases	Decreases	Target flow achieved
T50 time	Generally decreases	Increases	Controlled flow rate
V-funnel time	Decreases	Increases	Suitable viscosity
L-box ratio	Usually improves	Excessive dosage may reduce	Good passing ability
Segregation	May increase at high dosage	Decreases	High stability
Bleeding	May increase at excessive SP	Decreases	Reduced bleeding
Cohesion	May decrease	Increases	Balanced cohesion
Robustness	Moderate	Strongly improves	Improved production consistency

An important advantage of VMA is its ability to make SCC less sensitive to small variations in aggregate moisture. EFNARC notes that normal variations in aggregate moisture can significantly alter free-water content and therefore influence flow and cohesion; VMA can increase the robustness of the mixture against such variations.

EFFECT ON COMPRESSIVE STRENGTH

Compressive strength is influenced indirectly and directly by SP and VMA. SP can improve strength by allowing a reduction in mixing water while maintaining workability. A lower water-to-binder ratio generally produces a denser cementitious matrix and higher compressive strength.

VMA has a more complex influence. At an optimum dosage, VMA may contribute to uniform particle suspension, reduced segregation and improved microstructural homogeneity. However, excessive VMA can increase viscosity and may interfere with workability, potentially causing inadequate consolidation or unfavorable pore structure.

Recent experimental research specifically examining combined SP and VMA dosages used 16 SCC mixtures and found that both admixtures significantly influenced fresh properties and 28-day compressive strength. Response-surface models showed very high coefficients of determination for fresh-property indicators, demonstrating the feasibility of systematic dosage optimization.

Table 3. General Relationship Between Admixture Dosage and Strength

Dosage Condition	Expected Fresh Behavior	Expected Strength
Low SP + low VMA	Poor flow and possible blocking	May be limited
Optimum SP + low VMA	Good flow	Good
Optimum SP + optimum VMA	High flow with stability	Generally high
High SP + low VMA	Very fluid, segregation risk	Variable

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High SP + high VMA	Excessive interaction possible	Variable
Low SP + high VMA	Cohesive but stiff	Potentially reduced
Excessive VMA	Very viscous	May reduce effective compaction

EFFECT ON DURABILITY

Durability is one of the most important long-term performance characteristics of SCC. Concrete durability is strongly influenced by porosity, pore connectivity, permeability, cracking and resistance to aggressive environmental agents.

An optimized SP dosage can reduce water demand and consequently reduce capillary porosity. A dense matrix can provide greater resistance to the penetration of chloride ions, water and other aggressive substances.

VMA may contribute to durability by reducing segregation and bleeding. Improved stability can result in a more homogeneous microstructure with fewer localized defects. Recent reviews indicate that VMAs can influence not only rheological behavior but also hydration, microstructure, transport behavior and long-term durability.

Table 4. Durability Effects of Combined SP–VMA Systems

Durability Parameter	Role of SP	Role of VMA	Combined Potential
Water absorption	Can decrease through lower water demand	May improve matrix uniformity	Reduced absorption
Permeability	Reduced with lower w/b ratio	Reduced segregation-related defects	Lower permeability
Chloride penetration	Dense matrix improves resistance	Better homogeneity	Improved resistance
Sulfate resistance	Depends on binder system	Stability may assist matrix quality	Potential improvement
Freeze–thaw resistance	Depends on pore structure	Reduced defects	Potential improvement
Shrinkage	Indirect effect through water reduction	May influence moisture distribution	Mix-dependent
Cracking	Depends on mixture and curing	Excessive viscosity may affect placement	Optimum dosage beneficial
Carbonation	Dense matrix can slow CO_2 transport	Improved uniformity	Potentially improved

A review of SCC durability studies has also reported the use of SP and VMA together with supplementary cementitious materials and durability testing such as rapid chloride penetration, showing the importance of admixture optimization in achieving both workability and durability.

INFLUENCE ON RHEOLOGICAL BEHAVIOR

The rheological behavior of SCC is commonly described using yield stress and plastic viscosity. Yield stress represents the minimum stress necessary to initiate flow, whereas plastic viscosity describes the resistance to flow after movement has begun.

SP mainly reduces yield stress. VMA primarily increases plastic viscosity. This distinction explains why their combination is particularly useful for SCC.

A successful SCC mixture generally requires:

Low yield stress + controlled plastic viscosity = high flowability + segregation resistance

If yield stress is too high, the concrete cannot adequately fill the formwork. If plastic viscosity is too low, segregation may occur. Conversely, excessive plastic viscosity makes placement difficult and can increase V-funnel time.

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INTERACTION WITH CEMENT AND SUPPLEMENTARY CEMENTITIOUS MATERIALS

The effectiveness of SP and VMA is strongly influenced by the binder system. Fly ash, slag, silica fume, metakaolin and other supplementary cementitious materials can modify water demand, particle packing, surface area and admixture adsorption.

Fly ash can improve flowability because of its particle shape and packing characteristics, while silica fume generally increases viscosity because of its extremely fine particles and high surface area. Consequently, the required SP–VMA balance changes according to the supplementary material used.

This means that a dosage found suitable for one SCC mixture cannot automatically be transferred to another mixture. Cement type, mineral additions, aggregate grading and chemical admixture compatibility must be considered together.

COMPARATIVE REVIEW OF RESEARCH FINDINGS

Table 5. Representative Literature Findings

Study/Source	Main Focus	Major Finding
EFNARC European SCC Guidelines (2005)	SCC specification and production	SCC requires controlled filling ability, passing ability and segregation resistance
EFNARC VMA Guidelines (2006)	VMA applications	VMA improves cohesion, robustness and segregation resistance
Khayat and related VMA research	VMA–SP interaction	Proper VMA/SP combinations can produce fluid and cohesive mixtures
Recent VMA review (2026)	VMA mechanisms and durability	VMA effects extend from rheology to hydration, microstructure and long-term durability
Recent SP–VMA optimization study (2026)	Statistical optimization	Combined dosage strongly affects fresh properties and compressive strength
SCC durability review (2021)	Strength and durability	Proper admixture and supplementary-material combinations can improve SCC durability

EFNARC's VMA guidance classifies combination-type SCC as a mixture in which rheology is controlled by both VMA and an appropriate SP dosage. The 2026 optimization study further demonstrates the current movement toward quantitative optimization rather than empirical trial-and-error dosage selection.

ADVANTAGES OF COMBINED SP AND VMA

The major advantages of combining superplasticizer and VMA include:

High flowability without excessive water.

Improved resistance to segregation.

Reduced bleeding.

Better passing ability around reinforcement.

Greater robustness against aggregate-moisture variations.

Possibility of reducing powder content.

Improved surface finish.

Better control of rheological properties.

Potentially improved compressive strength.

Potential reduction in permeability.

Improved suitability for congested reinforcement.

Greater consistency during concrete production.

EFNARC specifically identifies improved robustness, reduced segregation and bleeding, better surface appearance and the possibility of using more fluid mixtures as important benefits of VMA in SCC.

II. CONCLUSION

The combined application of superplasticizers and viscosity-modifying admixtures represents an effective strategy for controlling the fresh and hardened performance of self-compacting concrete. Superplasticizers provide the high fluidity required for self-compaction primarily by reducing particle flocculation and yield stress, while VMAs increase cohesion and plastic viscosity and reduce segregation and bleeding. The combination therefore allows engineers to obtain SCC that is simultaneously highly flowable and stable.

The literature indicates that the optimum SP–VMA balance can improve fresh properties and may contribute to higher compressive strength and better durability by reducing water demand, improving homogeneity and controlling transport pathways. However, neither admixture should be used simply by increasing dosage. Excessive SP can cause instability, whereas excessive VMA can make concrete overly viscous and difficult to place. Therefore, admixture compatibility, binder composition, aggregate characteristics and environmental conditions must be considered during mixture development.

Overall, the most promising approach is an optimized, performance-based SP–VMA system in which yield stress and plastic viscosity are controlled together. Current research is moving toward statistical and computational optimization, low-carbon binders and a better mechanistic understanding of VMA effects on microstructure and long-term durability. Such developments can further increase the reliability, sustainability and structural applications of SCC.

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