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PREDICTION OF MECHANICAL PROPERTIES OF SELF COMPACTING CONCRETE USING RESPONSE SURFACE METHODOLOGY

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INTRODUCTION

1.0 General

Self-Compacting Concrete (SCC) is a highly flowable concrete that can spread and consolidate under its own weight without the need for mechanical vibration. It is widely used in modern construction due to its excellent workability and ability to fill complex formwork with congested reinforcement. Predicting the mechanical properties of SCC, such as compressive strength and split tensile strength, is important for achieving reliable and optimized mix designs. Response Surface Methodology (RSM) is a statistical and mathematical technique used to analyze the relationship between input variables and output responses. In this study, RSM is used to predict and optimize the mechanical properties of SCC by analyzing the effects of different mix parameters.

1.1 INTRODUCTION

Concrete is the most widely used construction material in the world due to its high compressive strength, durability, economy, and ability to be moulded into any desired shape. It plays a vital role in the construction of buildings, bridges, dams, roads, and many other civil engineering structures. Conventional concrete requires proper mixing, placing, compaction, and curing to achieve the required strength and durability. Among these processes, compaction is one of the most important steps, as it removes entrapped air from the concrete and ensures full contact between aggregates and cement paste. Normally, compaction is done using mechanical vibration. However, in structures with congested reinforcement, complex formwork, or difficult placing conditions, proper vibration becomes very difficult. Inadequate compaction leads to defects such as honeycombing, voids, segregation, and poor surface finish, which reduce the strength and durability of concrete.

To overcome these difficulties, Self Compacting Concrete (SCC) was developed as an advanced type of concrete that can flow under its own weight and completely fill the formwork without the need for external vibration. SCC was first developed in Japan in the late 1980s to improve construction quality and to reduce the dependence on skilled labor. Self Compacting Concrete has three main characteristics: high flowability, passing ability, and resistance to segregation. Flowability allows the concrete to spread easily, passing ability enables it to flow through congested reinforcement without blocking, and segregation resistance ensures uniform distribution of aggregates without separation. Because of these properties, SCC provides better surface finish, improved durability, reduced noise during construction, and faster placing compared to conventional concrete.

Self-Compacting Concrete is widely used in modern construction, especially in heavily reinforced structural members such as beams, columns, shear walls, foundations, and precast concrete elements. The use of SCC reduces labor requirements, improves safety at construction sites, and ensures uniform quality of concrete. In addition, SCC is very useful in high-rise buildings, bridges, tunnels, and complex architectural structures where proper compaction is difficult to achieve. Due to these advantages, Self Compacting Concrete has become an important development in modern concrete technology.

This research focuses on studying the fresh and hardened properties of Self Compacting Concrete. Fresh properties such as slump flow, V-funnel time, and L-box test indicate the flowability, viscosity, and passing ability of SCC. Hardened properties such as compressive strength, split tensile strength, and flexural strength represent the mechanical performance and load carrying capacity of the concrete. Evaluating these properties helps in understanding the behaviour and performance of Self Compacting Concrete in different structural applications.

This study contributes to the development of high-performance and durable Self Compacting Concrete suitable for modern construction practices. The results can help engineers and researchers in designing concrete mixes that provide better workability, strength, and durability for various civil engineering structures.

1.1.2 Fly-Ash

Fly ash is a fine powder by-product obtained from the combustion of coal in thermal power plants. It is widely used as a supplementary cementitious material in concrete due to its beneficial physical and chemical properties. The fine particles of fly ash improve the workability and flowability of concrete mixes, especially in Self-Compacting Concrete. It also reduces the heat of hydration and enhances long-term strength and durability through pozzolanic reactions with calcium hydroxide produced during cement hydration. The use of fly ash helps in reducing cement consumption, which lowers carbon dioxide emissions and promotes sustainable construction practices. Therefore, fly ash plays an important role in producing economical, durable, and environmentally friendly concrete.

1.1.3 Steel Fiber

Steel fibers are short, discrete lengths of steel that are added to concrete to improve its mechanical properties. Conventional concrete is strong in compression but weak in tension and susceptible to cracking. The addition of steel fibers helps to improve tensile strength, ductility, toughness, and crack resistance of concrete. Steel fibers also enhance the impact resistance and energy absorption capacity of concrete structures. In Self-Compacting Concrete, steel fibers help in controlling plastic shrinkage cracks and improve the post-cracking behavior of concrete. Due to these advantages, steel fiber reinforced concrete is widely used in pavements, industrial floors, tunnels, bridges, and precast structural elements.

1.1.4 Superplasticizer

Superplasticizers are high-range water-reducing chemical admixtures used in concrete to improve workability without increasing the water content. They help in producing highly flowable concrete while maintaining high strength and durability. In Self-Compacting Concrete, superplasticizers play a crucial role in achieving the required flowability and self-compaction properties. By reducing the water-cement ratio, superplasticizers increase the strength and density of concrete while preventing segregation. They also improve the dispersion of cement particles, resulting in better hydration and improved mechanical properties. Therefore, superplasticizers are essential for producing high-performance and self-compacting concrete mixes.

1.1.5 Response Surface Methodology

Design of Experiments (DOE) is a systematic approach used to study the effect of multiple variables on the performance of a system. In concrete research, DOE helps in reducing the number of experimental trials while obtaining reliable and optimized results. One of the commonly used experimental designs in Response Surface Methodology (RSM) is the Central Composite Design (CCD). CCD is used to develop mathematical models that describe the relationship between input variables and output responses. It consists of factorial points, axial points, and center points which help in analyzing both linear and quadratic effects of variables. In the present study, CCD is used to evaluate the combined effects of different mix parameters on the mechanical properties of Self-Compacting Concrete. This method helps in predicting the strength properties and determining the optimal mix proportions with minimum experimental effort.

CHAPTER – 2

LITERATURE REVIEW

2.0 Introduction:

The literature which are closed or related to Prediction of Mechanical Properties of Self Compacting Concrete Using Response Surface Methodology.

2.1 Review of Literature:

S.no	Author	year	Title	Remarks
1	Ángel De La Rosaa, Gonzalo Ruizb	2025	Mix design methodology for self-compacting flexible-fiber reinforced concrete based on rheological and mechanical concepts.	Portland cement (CEM I 52.5 N–SR), limestone powder as mineral filler, fine and coarse aggregates, water, poly-aryl ether–based superplasticizer, and flexible fibers such as PVA and polypropylene were used. Cement hydration produces C–S–H gel and $Ca(OH)_2$, which contributes to strength. Fresh and hardened concrete were evaluated using the slump flow test, L-box test, and compressive strength test. The mixes achieved a slump flow of 700–800 mm, L-box ratio of 0.93–1.00, and compressive strength of 33–47 MPa. The concrete is suitable for heavily reinforced structures, precast elements, industrial floors, and tunnel linings.SCC flow behavior, and proper fiber selection improves ductility, crack resistance, and durability while maintaining self-compactability
2	Yuchen Guo a a,b,* , Hao Su b , Siqi Wang	2025	Study on the properties of high-performance semi-flowable self-compacting concrete suitable for	Ordinary Portland Cement (P·O 42.5), natural sand, crushed limestone aggregate (5–20 mm), fly ash, metakaolin, cellulose fiber, chemical admixtures, and water. Cement hydration forms C–S–H gel

			road works.	and $Ca(OH)_2$ for basic strength. Fly ash and metakaolin react with $Ca(OH)_2$ to produce additional C–S–H and C–A–H, improving early and long-term strength while densifying the concrete matrix.Slump flow, L-box, segregation resistance, compressive strength (3 & 28 days), splitting tensile strength.The optimal mix (26.48% fly ash + 2.5% metakaolin) showed improved flowability, about 25% higher compressive strength.Vibration-free pavement works, and durable road infrastructure.
3	Yang Wen a a,b , Shaojie Zheng a,* , Miao Li a,c , Chengjun Peng	2025	Bond-slip behavior of rectangular steel tubes filled with self-compacting and self-stressing concrete	Rectangular and square steel tubes, self-compacting self-stressing concrete using sulfoaluminate cement, fine and coarse aggregates, fly ash, and a high-range water-reducing admixture. Cement hydration causes micro-expansion; steel tubes create self-stress, improving bond via chemical, frictional, and mechanical effects. Push-out test, slump flow & T_{500}, compressive strength. Bond strength 0.92–1.60 MPa, 2.6–4.5× higher than normal; steel thickness and self-stress boosted strength; prediction model MAPE = 6.22%. Rectangular CFST columns for high-rise and heavy-load structures benefit from self-stressing SCC, which significantly improves steel–concrete bond, with steel tube thickness being the most influential factor.
4	Jinping Zhuang a a,b,1 , Yangzhen Chen b,1 , Rongxin Xu b,1 , Jianxing Chen c	2025	Compressive performance of steel fiber reinforced rubber self-compacting concrete after high-temperature exposure	Self-compacting concrete with rubber (10% sand) and 1% steel fibers showed improved ductility and fire resistance. Cement hydration forms C–S–H gel, rubber softens at high temperatures, and steel fibers bridge cracks to reduce strength loss. Key tests included slump flow, compressive strength, and high-temperature

				exposure. Results showed 34–90% higher residual strength at 600–900 °C. Applications include fire-resistant structures and sustainable construction, and the study shows that steel fibers effectively compensate for rubber's strength loss, with 1% being optimal.
5	Xinxin Ding a, c Shunbo Zhao a,c , Wenlei Jia a a,c , Changyong Li a, b,* , Haibin Geng a, Gonglian Chen	2025	Study on the meso-scale numerical simulation method for flow behavior of fresh self-compacting steel fiber reinforced concrete based on DEM-SPH coupling	Self-compacting SFRC with steel fibers (~0.8%) and fly ash showed uniform fiber dispersion and minimal aggregate segregation. Cement hydration and pozzolanic reaction provide strength, while fibers bridge cracks. Key tests included slump flow, L-box, and slab casting. Applications include slabs, pavements, and structural elements, and numerical modeling (DEM–SPH) helps predict flow and fiber orientation, reducing trial-and-error.
6	Meng He a a , Lijuan Zhang a,* , Jun Zhao b,**	2025	A review of mixture design methods for self-compacting recycled concrete	Self- compacting concrete aggregates and supplementary cementitious materials (fly ash, slag, silica fume) offers a sustainable, low-carbon solution. Cement hydration and pozzolanic reactions provide strength, while recycled aggregates may slightly reduce workability and compressive strength. Key tests include slump flow, L-box/J-ring, and compressive strength. With proper mix-design (EMV, rheology-based, or packing methods), SCRC achieves good flow (600–800 mm), acceptable durability, and uniform microstructure. Applications include buildings, bridges, pavements, tunnels, and other infrastructure, and the study shows that considering aggregate properties and old mortar is essential for reliable, resource-efficient concrete.
7	Zhiwen An a ,	2025	Effect of curing age	Track Slab Concrete (TSC) and

	Lei Qin a,c,* , Chengchao Guo a,b,c,d,**, Leiyang Pei a , Feifan Shi a		on the bonding performance of the interface between track slab concrete and self-compacting concrete	Self-Compacting Concrete (SCC) with cement, fly ash, and mineral powder show improved interfacial shear strength with curing age, reaching 1.275 MPa at 56 days. Key tests include push-out shear, compressive strength, and Acoustic Emission (AE) monitoring, which track bonding and crack evolution. Applications include CRTS III high-speed rail slab tracks and concrete-to-concrete composite structures. The study highlights that curing age and enhanced hydration are critical for strong, durable TSC–SCC interfaces, and AE monitoring is effective for assessing interface performance.
8	Ángel De La Rosa a ,*, Gonzalo Ruiz b, Rodrigo Moreno	2025	Mineral additions as pigments and mechanical property enhancers in self-compacting natural hydraulic lime concrete	Self-compacting NHL-5 lime concrete with pozzolanic pigments (red silt clay, ultramarine blue) showed good flowability, compressive strength (~25–27 MPa), and improved flexural performance. Key tests included mini-cone flow, compressive, and bending tests. Pozzolanic pigments reacted with $Ca(OH)_2$, producing additional C–S–H/C–A–S–H gels, reducing porosity and densifying the matrix. Fly ash steel fiber Applications include architectural, decorative, and sustainable low-CO_2 construction, as well as restoration works. The study demonstrates that natural pigments can enhance both aesthetics and structural durability, making lime-based SCC a viable eco-friendly alternative to Portland cement concrete.
9	Bin Ye a,b , Jingjun Li a,b,* , Juan Li a,b , Enjia Zhao c , Zongjie Ma a,b	2025	Effect of steel fiber dosage on the uniaxial compressive behavior of self-compacting lightweight aggregate concrete	Self-compacting lightweight concrete (SCLC) was made with Portland cement, fly ash, silica fume, river sand, fly-ash ceramsite, and copper-coated steel fibers (0–1%). Cement hydration forms C–S–H gel, fly ash reacts pozzolanically, and hydration products

				enhance fiber–matrix bonding. Key tests included slump flow, J-ring, compressive and splitting tensile strength, and SEM. At 0.75% fiber, compressive strength increased 22%, splitting tensile strength 37.5%, and failure changed from brittle to ductile. Applications include high-rise, long-span, and precast structures requiring self-compaction and toughness. Steel fibers reduce brittleness and improve ductility, with 0.75% being optimal
10	Hadi Bahmani ,Davood Mostofinejad	2025	Sustainable self-compacting concrete: Performance optimization using calcium oxide-activated slag and sugar factory lime waste	Cementless SCC made with slag, CaO, and lime waste achieved high strength (compressive 54.3 MPa) and good flow (slump 718 mm). Key tests included slump flow, T_{50}, compressive strength, and SEM. Dense C–S–H microstructure was observed due to alkaline activation. Applications include precast elements and sustainable green construction, and the study shows industrial wastes can replace cement, with CaO improving strength and lime waste reducing carbon footprint. Proper activation ensures workable, durable, and eco-friendly SCC for practical construction use.
11	Pochara Kruavit a, Piti Sukontasukkul a,* , Woramet Jitprapakorn a	2025	Parametric and feasibility investigation on drone-assisted placement of self-compacting lightweight concrete	Drone-cast self-compacting lightweight concrete used cement, fly ash, sand, lightweight coarse aggregate, superplasticizer, VMA, water, and a quadcopter drone. Cement hydration and pozzolanic reactions formed C–S–H gel. Key tests included slump flow, L-box, compressive and flexural strength, and drone performance. Drone-cast concrete achieved slump flow ~660 mm, compressive strength 26.8 MPa, with minor strength reduction but acceptable performance. Applications include remote, hazardous, or hard-to-reach construction

				sites. Flowability is critical, and optimized mix and drone parameters enable feasible automated concrete placement.
12	Jie Zhou a , Jingbo Su a,* , Jiaming Liu a , Jian Yang a , Zhe Li a	2025	Acoustic emission behavior of CFRP-confined steel fiber-reinforced self-compacting lightweight aggregate concrete: Crack monitoring and damage assessment	Lightweight concrete with cement, fly ash, silica fume, steel fibers, and CFRP sheets was tested. Cement hydration and pozzolanic reactions formed C–S–H gel, while CFRP provided physical confinement. Key tests included axial compression, AE monitoring, and SEM. Combined steel fiber + CFRP improved toughness, changed failure from brittle to ductile, and controlled cracks. Applications include high-rise, seismic-resistant, and retrofitted structures. AE monitoring proved useful for real-time failure prediction and structural safety.
13	Sadegh Abedi Mavaramkolaei a, Mohammad Ali Sayarinejad a,*, Ali Nazari b	2025	Investigating the fracture behavior and ductility of self-compacting concrete containing recycled nylon granules:An experimental and modeling study	Self-compacting concrete (SCC) was made with Ordinary Portland Cement, fine & coarse aggregates, recycled nylon granules (0–15%), limestone powder, superplasticizer, and water. Cement hydration formed C–S–H gel for strength, while nylon did not react chemically but weakened the interface, increasing ductility. Key tests included slump flow, L-box, three-point bending, and SEM analysis. Increasing nylon content reduced compressive strength (~29%) but enhanced ductility and energy absorption. Applications include earthquake-resistant, impact-resistant, and sustainable structures. Nylon-based SCC provides resilient, less brittle concrete suitable for structures where ductility is critical.
14	Amol Sharma a ,Siddharth Garia b, R.C. Kale c,*	2025	Performance of self-compacting concrete modified with wollastonite fibre and silica fume	Self-compacting concrete (SCC) was made with OPC 53 grade, fine & coarse aggregates, silica fume (6%), wollastonite powder (5–30%), superplasticizer, and water. Cement

				hydration formed C–S–H gel, silica fume reacted pozzolanically, and wollastonite acted as micro-fibre for crack bridging. Key tests included slump flow, L-box, compressive strength, flexural strength, and SEM analysis. Strength improved with wollastonite up to 20% (compressive 45.11 MPa) due to matrix densification, while excess reduced workability. Applications include heavily reinforced structures, precast elements, and high-performance SCC construction. Wollastonite + silica fume improves strength, ductility, and durability, but optimal dosage is crucial.
15	Kishor Kalauni a , Peter Czirak a , Shashikant Chaturvedi a	2025	Performance and design considerations for heavyweight self-compacting concrete using magnetite and barite aggregates	Heavyweight self-compacting concrete (HWSCC) was made using OPC, heavyweight aggregates (magnetite/barite), fine aggregate, fly ash, GGBS, silica fume, superplasticizer, VMA, and water. Cement hydration formed C–S–H gel, and SCMs reacted pozzolanically, while heavy aggregates were inert and provided radiation shielding physically. Key tests included slump flow, L-box/J-ring, compressive strength, density measurement, and gamma-ray attenuation (HVL). HWSCC achieved high density (3400–3900 kg/m³), compressive strength 40–60 MPa, and effective radiation shielding. Applications include nuclear facilities, medical radiology rooms, and military bunkers. Proper mix design ensures uniform flow, structural reliability, and effective shielding.
16	Zhuohan Wang , Bo Wu	2025	Horizontal and vertical filling behaviors of self-compacting recycled aggregate concrete in recycled	Self-compacting recycled aggregate concrete (SCRLAC) was made using OPC 42.5R, fly ash, recycled sand, recycled coarse aggregate, recycled lumps, superplasticizer, and water. Cement hydration forms

			lump skeleton	C–S–H gel, and fly ash reacts pozzolanically; recycled aggregates are inert, contributing mainly through physical filling. Key tests included slump flow, horizontal & vertical filling tests, compressive strength, and ultrasonic testing. Results showed defect-free zones with low porosity (<0.7%) and uniform compressive strength, with best filling achieved at larger RL size and high slump flow. Applications include sustainable mass concrete, foundations, shear walls, and precast structures. Proper flowability and lump size ensure full filling and structural reliability, improving construction efficiency and sustainability.
17	Ángel De La Rosa a , Gonzalo Ruiz b	2025	Activation of autogenous self-healing in pozzolanic natural hydraulic self-compacting lime concrete under cyclic compressive loading	This study investigates self-healing in natural hydraulic lime concrete containing pozzolanic materials such as metakaolin, silica fume, and fly ash. When subjected to cyclic compressive loading, chemical reactions like carbonation ($Ca(OH)_2$ reacting with CO_2 to form $CaCO_3$) and pozzolanic reactions occur, which help fill microcracks. Tests such as cyclic fatigue loading, compressive strength testing, and microstructural analysis (TGA and XRD) showed an increase in strength and stiffness after loading. The results indicate that cyclic loading activates autogenous self-healing, making this eco-friendly concrete suitable for sustainable construction and restoration of heritage structures.
18	Rumeysa Utu a , Metin Katlav b,* , Izzeddin Donmez c , Ceren Kina d , Kazim Turk a	2025	Research on bond behavior between steel rebar and self-compacting geopolymer concrete (SCGC) containing recycled aggregate by large-	This study examines self-compacting geopolymer concrete made with recycled aggregates, using silica fume, slag, fly ash, and a hybrid activator of calcium hydroxide and sodium silicate. Geopolymerization reactions form strong binding gels, and tests such

			scale Beams.	as four-point bending and bond strength tests showed improved steel–concrete interaction. Results indicate that binary precursor mixes with lower activator content give higher bond strength, highlighting SCGC as a sustainable and structurally reliable concrete.
19	Ali Ejaz a , Muhammad Adnan Hanif b , Burachat Chatveera	2025	Development of nano-calcium carbonate modified green self-compacting concrete incorporating recycled tempered glass and waste cotton rope fibers	This study focuses on sustainable concrete using alternative binders and recycled materials. The main materials include supplementary cementitious materials (such as fly ash/slag/silica fume), aggregates, water, and chemical activators or lime. The key chemical reactions involved are geopolymerization or carbonation–pozzolanic reactions, which form binding gels (C–S–H / C–A–S–H) and help improve strength and crack healing. Tests like compressive strength test, bond or flexural test, and microstructural analysis (XRD/TGA) were conducted. Results showed improved strength and durability, while the study highlights applications in eco-friendly construction and teaches that proper material combination and reactions can significantly enhance sustainable concrete performance.
20	Mohamed Abdulqadir Mohamed a, Amin Al-Fakih a,b,*, Rida Assaggaf b,Mohamed Harun a	2025	Limestone Calcined Clay Cement-based rubberized self-compacting concrete: Fresh, mechanical, durability, and embodied-carbon assessment	This study focuses on sustainable concrete made using alternative binders such as fly ash, slag or silica fume along with aggregates, water, and chemical activators or lime. The main chemical reactions involved are geopolymerization or pozzolanic–carbonation reactions, which form strong binding gels like C–S–H or C–A–S–H and improve strength and durability. Tests such as compressive strength test, flexural or bond strength test, and microstructural analysis (XRD/TGA) were conducted. Results showed improved

				mechanical performance and durability, indicating that such concrete is suitable for eco-friendly construction. The study teaches that proper material selection and chemical reactions can significantly enhance sustainable and durable concrete behavior

2.2 Scope of the work:

Based on the reviewed literature, Self-Compacting Concrete (SCC) has gained significant attention in recent years due to its ability to flow and consolidate under its own weight without the need for mechanical vibration. Researchers have explored different mix design methods, supplementary cementitious materials, fibers, and recycled materials to enhance the mechanical and durability properties of SCC. These studies have shown that SCC can achieve excellent workability, high strength, improved durability, and better crack resistance when appropriate materials and mix proportions are used. Various experimental investigations have also focused on evaluating the fresh properties of SCC such as slump flow, L-box, and segregation resistance, as well as hardened properties like compressive strength, tensile strength, and flexural strength. However, despite extensive research, achieving the optimal balance between workability, strength, and durability remains a challenge because SCC performance depends on several interacting parameters. Therefore, further systematic investigation is required to understand the influence of mix components and their proportions on the overall behavior of Self-Compacting Concrete.

The significance of this research lies in contributing to the development of high-performance and reliable Self-Compacting Concrete for modern construction practices. SCC offers several advantages over conventional concrete, including improved flowability, reduced construction time, better surface finish, and elimination of noise and labor associated with vibration. These benefits make SCC highly suitable for heavily reinforced structural elements, complex formworks, precast components, bridges, tunnels, and high-rise buildings. By studying the relationship between different mix parameters and the mechanical properties of SCC, this work helps in identifying suitable mix proportions that provide both good workability and high strength. The findings of this study can assist engineers and researchers in designing efficient SCC mixes that meet structural and durability requirements while ensuring ease of placement. Ultimately, the research supports the advancement of sustainable and durable concrete technology, which is essential for meeting the growing demands of modern infrastructure development.