



INVESTIGATION OF CHEMICAL DURABILITY PARAMETERS OF MINERALS AND ADMIXTURE BLENDED SUSTAINABLE SELF COMPACTING CONCRETE(SCC)

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ABSTRACT

Self-Compacting Concrete (SCC) has also attracted a lot of attention in contemporary construction with its added advantage of workability, lower labour demands, and free flow under its own weight without the need for mechanical vibration. In its bid to be more environmentally friendly, researchers are looking into the addition of supplementary cementitious materials (SCMs) like fly ash, ground granulated blast furnace slag (GGBS), silica fume, and metakaolin, as well as chemical admixtures. Although these materials contribute to lowering the carbon footprint of concrete production, their impact on chemical durability is yet to be determined.

This research is centred on assessing chemical durability parameters of green SCC using mineral and admixture blends. Important factors to be studied include chloride penetration resistance, sulfate resistance to attack, carbonation depth, and alkali-silica reaction susceptibility. Accelerated durability testing, X-ray diffraction (XRD), scanning electron microscopy (SEM), and mercury intrusion porosimetry (MIP) experimental methods will be utilized to analyse microstructural alteration and chemical interactions within the concrete.

Keywords: Self-compacting concrete (SCC), chemical durability, mineral admixtures, sulfate resistance, chloride penetration, sustainable construction.

INTRODUCTION

Self-Compacting Concrete (SCC) is a flowing concrete mixture that can consolidate under its weight. It is gaining prominence in construction due to its superior workability and reduced labour requirements. To enhance its environmental performance, researchers are exploring the incorporation of minerals and admixtures, such as industrial by-products and natural pozzolans, into SCC mixtures.

While these additives can reduce the carbon footprint of concrete production, their impact on chemical durability requires further investigation. This study aims to examine the chemical durability parameters of sustainable SCC incorporating various minerals and admixtures. The research will focus on chloride penetration resistance, sulphate attack resistance, carbonation depth, and alkali-silica reaction potential. By analyzing these aspects, we seek to understand how these additives affect the long-term durability of SCC in chemically aggressive environments. The findings will contribute to developing more resilient and environmentally friendly concrete mixtures, potentially improving guidelines for sustainable SCC design and application in construction projects. Additionally, this research may identify optimal combinations of minerals and admixtures that enhance both the sustainability and durability of SCC.

To enhance its environmental performance, researchers are exploring the incorporation of minerals and admixtures, such as industrial by-products and natural pozzolans, into SCC mixtures (Siddique, 2011). These supplementary cementitious materials (SCMs) can partially replace traditional Portland cement, leading to a reduction in the overall carbon footprint of concrete production. Common

SCMs include fly ash, ground granulated blast furnace slag, silica fume, and metakaolin, each offering unique benefits in terms of workability, strength development, and durability.

While these additives can reduce the carbon footprint of concrete production, their impact on chemical durability requires further investigation (Mehta and Monteiro, 2014). The long-term

performance of concrete structures in aggressive environments is crucial for ensuring their serviceability and longevity. The incorporation of minerals and admixtures can significantly alter the microstructure and chemical composition of the concrete matrix, potentially affecting its resistance to various deterioration mechanisms.

By analyzing these aspects, we seek to understand how these additives affect the long-term durability of SCC in chemically aggressive environments. The study will employ various experimental techniques, including accelerated testing methods, to assess the performance of different SCC mixtures under controlled conditions. Advanced analytical tools, such as X-ray diffraction (XRD), scanning electron microscopy (SEM), and mercury intrusion porosimetry (MIP), will be utilized to characterize the microstructural changes and chemical interactions within the concrete matrix. The findings will contribute to developing more resilient and environmentally friendly concrete mixtures, potentially improving guidelines for sustainable SCC design and application in construction projects. By identifying the optimal combinations of minerals and admixtures that enhance both sustainability and durability, this research aims to bridge the gap between environmental considerations and long-term performance requirements in concrete technology.



PHYSICAL PROPERTIES

The physical properties of mineral admixtures, such as particle size, specific surface area, and specific gravity, play a critical role in determining the performance of concrete mixtures. Silica fume is a fine, gray or white powder with spherical particles that are less than 1 μm in diameter, making them nearly 100 times smaller than typical cement particles. It has a high specific surface area ranging from 13,000 to 30,000 m²/kg, which significantly enhances its pozzolanic reactivity. In contrast, fly ash (FA) has a soft gray color, with particle sizes between 10 μm and 100 μm, and most particles smaller than 35 μm. Its surface area typically ranges from 300 to 500 m²/kg, with extreme values between 170 and 1000 m²/kg, and a specific gravity between 1.9 and 2.55.

Coal bottom ash (CBA), on the other hand, is a dark gray, porous material that turns black after grinding. It has an irregular structure, with a specific gravity ranging from 1.39 to 2.47, depending on the combustion technique used. The high porosity of CBA results in increased water absorption, varying from 5.45% to 32.2%, which can affect the workability of concrete. Its modulus of fineness ranges from 1.37 to 3.44, reflecting the variability in particle size distribution. These physical characteristics, along with those of other admixtures like GGBS, influence the fresh and hardened properties of concrete, including workability, water absorption, and strength development.

Physical characteristics/ mineral admixture type	Fly Ash (%)	Silica Fume (%)	GGBS (%)
Shape	Spherical	Spherical	Spherical
Specific gravity	1.9–2.55	2.25	2.6
Average particle size	0.5–300 μ-m	0.1μ	4.75 mm down
Bulk density (Kg/m³)	540–860	750–850	1000–1100

Fineness modulus	-	-	-
Water absorption (%)	-	-	-

Table 1. Physical Characteristics of Mineral Admixtures

CHEMICAL PROPERTIES

The chemical composition of coal bottom ash (CBA) varies depending on its source and combustion method. CBA predominantly consists of alumina, silica, and iron, which together make up about 70% of its overall composition, qualifying it as a pozzolanic material under ASTM C618 standards (Class C or F). However, the large particle size of CBA reduces its pozzolanic reactivity. This limitation can be mitigated by finer grinding, which increases the reactivity of its silica content, thereby improving its performance in concrete applications. The loss on ignition (LOI) for CBA typically ranges from 0.89% to 8.10%, indicating varying levels of unburned carbon.

The chemical composition of fly ash is influenced not only by the type of coal used but also by the combustion process, including factors such as boiler design, combustion temperature, and particle size. Fly ash is primarily composed of aluminosilicate compounds with varying amounts of metallic oxides and calcium oxides. Enders et al. noted that the consistency of $Al_2O_3 + SiO_2$ in fly ash spheres suggests they originate from coal’s kaolinite. Fly ash also contains trace elements like Cr, Ba, Ni, Pb, Sr, V, and Zn, which are often found in magnetospheres. Additionally, as fly ash hydrates, it helps reduce the leaching of heavy metals, thereby enhancing its environmental performance in concrete mixtures.

Silica fume is characterized by a high concentration of amorphous silicon dioxide and very fine, spherical particles. Its chemical composition also includes trace amounts of magnesium, iron, and alkali oxides, which enhance its pozzolanic reactivity and make it highly effective as a cementitious material. The inclusion of silica fume in concrete improves both strength and durability by contributing to the development of a denser microstructure. Similarly, GGBS (Ground Granulated Blast-Furnace Slag), like other pozzolanic materials, contributes to the chemical and mechanical enhancement of concrete when used in combination with other mineral admixtures and is provided in Table based on several previous studies.

Granulated Blast Furnace Slag (GGBS) is a byproduct of the iron and steel industry, obtained by rapidly cooling molten slag from a blast furnace with water or air. This cooling process forms granules, which are then dried and ground into a fine powder for use in cement and concrete applications. Granulated Blast Furnace Slag (GGBS) is an industrial byproduct derived from the steel manufacturing process, specifically from blast furnaces used in iron production. It is widely used in the construction industry as a supplementary cementitious material (SCM) to partially replace Ordinary Portland Cement (OPC) in concrete. GGBS enhances the durability, sustainability, and strength of concrete structures, making it an essential component in high-performance concrete, self-compacting concrete, and blended cement production.

Chemical elements/ References and type of admixture	Fly Ash (%)	Silica Fume (%)	GGBS (%)
SiO2	25–60	95.75	27–38
Al2O3	10–30	0.35	13.24
Fe2O3	5–25	0.21	0.65
CaO	<10	0.17	34–43
MgO	<1	0.09	0.15–0.76
SO3	<1	0.42	<1
K2O	<1	<1	0.37
Na2O	<1	0.51	<1

Table 2. Chemical Properties of Mineral Admixtures

FRESH PROPERTIES

The fresh state properties of Self-Compacting Concrete (SCC) are critical for its mechanical strength and structural performance. SCC is designed to fill formwork completely and encapsulate reinforcement, even in heavily reinforced sections, without the need for vibration, thereby preventing cracks and segregation during casting. Its superior fluidity allows it to flow through complex reinforcement layouts like a viscous fluid. Nataraja et al. developed a method to produce SCC tailored to strength requirements by modifying the IS 10262:2009 guidelines, while adhering to EFNARC standards. Their study established a correlation between the water-cementitious ratio and compressive strength using 25 mix ratios, optimizing the balance between

flowability and strength.

Various studies have explored the impact of cement replacement materials, such as fly ash, on SCC’s fresh properties. Dar et al. tested different fly ash replacement ratios (5% to 35%) and found that a 30% substitution achieved optimal flowability and mechanical properties, as determined through slump flow tests and other assessments. Similarly, Gesoğlu examined SCC mixes with silica fume (SF) at replacement levels of 5%, 10%, and 15%. The study revealed that SF increases the viscosity and flow time, with slump flow radii ranging from 67 to 69.5 cm and L-box height ratios improving with higher SF content. These findings indicate that mineral admixtures enhance SCC's viscosity and flow characteristics, adhering to EFNARC guidelines.

A number of studies have explored the effect of Ground Granulated Blast Furnace Slag (GGBS) on the fresh properties of Self-Compacting Concrete (SCC). Al-Oran et al. Tested SCC with GGBS replacement percentages of 15%, 20%, 25%, and 30% along with a fixed 10% metakaolin (Mk) replacement. The findings revealed that GGBS improved flowability and other fresh characteristics to a 25% replacement. The addition of metakaolin with GGBS, though, decreased fresh performance. Measured slump flow was between 690–720 mm, the T50 cm time between 2.7–3.2 seconds, the L-box height ratio between 0.85–0.92, and the V-funnel flow time between 7.5–11 seconds, all below the EFNARC standard thresholds for SCC. A number of studies have examined the effect of Ground Granulated Blast Furnace Slag (GGBS) on the fresh properties of Self-Compacting Concrete (SCC).

Tested SCC with 15%, 20%, 25%, and 30% GGBS replacement levels, in addition to a constant 10% metakaolin (Mk) substitution. The findings indicated that GGBS improved the flowability and other fresh properties up to a 25% substitution level. Nevertheless, the addition of metakaolin in combination with GGBS lowered the fresh performance. The slump flow value measured was 690–720 mm, the T50 cm time was 2.7–3.2 seconds, the L-box height ratio was 0.85–0.92, and the V-funnel flow time was 7.5–11 seconds, all within the EFNARC standard limits for SCC.

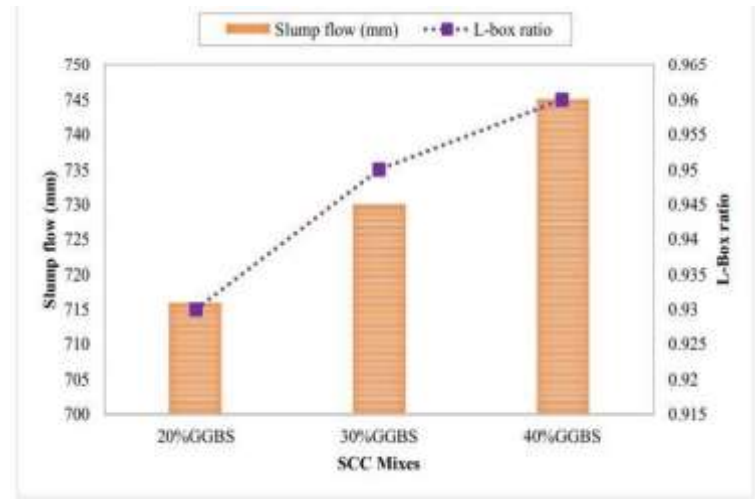


Figure 1. Fresh properties of GGBS in SCC

SLUMP FLOW TEST

Horizontal spread of SCC under its own weight is measured through a slump flow test. This test analyze the flowability and uniformity of concrete. A diameter between 650–800 mm of the target slump flow is generally acceptable. The inclusion of mineral admixtures such as fly ash and GGBS in SCC improves its flowability, since particles are fine in size and have smooth surfaces with reduced particle-to-particle internal friction.

The slump flow test not only provides insights into the workability of SCC but also serves as a key indicator of its passing ability and segregation resistance. A higher slump flow indicates better flowability, allowing the concrete to fill intricate formwork and densely reinforced areas without the need for mechanical vibration. However, excessive flow may lead to segregation, where the coarse aggregates separate from the paste, compromising the concrete's homogeneity and durability. Therefore, achieving an optimal slump flow within the recommended range is critical for balancing flowability with stability, ensuring that the SCC can maintain its cohesiveness during placement.

Additionally, the T50 time, which measures the time taken for the SCC to reach a 50 cm spread, provides valuable information about the concrete's viscosity and flow speed. A shorter T50 time indicates a more fluid mix, while a longer time suggests a more viscous or stiff mixture. The ideal T50 time typically ranges between 2 to 5 seconds, depending on the specific project requirements. This parameter is crucial for applications where controlled flow rates are necessary to prevent excessive spreading or segregation. Overall, the slump flow test, along with other fresh property tests such as the V-funnel and L-box tests, plays a vital role in ensuring that SCC meets both workability and performance standards in modern construction.

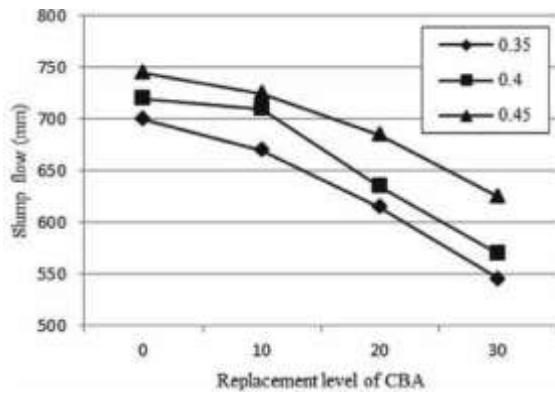
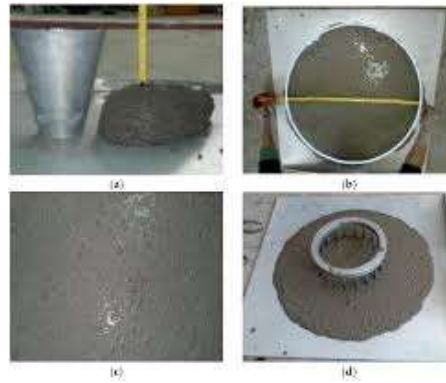


Figure 2. The CBA Slump flow Test in SCC



SLUMP FLOW

L-BOX TEST

The L-box test is one of the common tests for testing the passing ability and flow characteristics of Self-Compacting Concrete (SCC) through tight reinforcement or tight formwork. The test is a simple means of testing the ability of SCC to flow due to its weight while being homogenous and fill tight spaces without segregation. The L-box apparatus is made up of an upper vertical part where the SCC is filled, and a lower horizontal part with reinforcement bars that mimic actual structural conditions. When the gate that divides the two parts is opened, the SCC flows horizontally, simulating its behaviour at the time of placement in reinforced structures.

One of the main parameters in the L-box test is the height ratio (H_2/H_1), the ratio of the final concrete height at the end of the horizontal section (H_2) to the initial height in the vertical section (H_1). The ratio, referred to as the blocking ratio, is a measure of the ability of the SCC to flow over obstacles, including reinforcing bars. A ratio approaching 1.0 represents high passing capability with little blockage, and a lower ratio represents blocked flow. An L-box height ratio of 0.8 to 1.0 is normally acceptable for SCC according to the EFNARC guidelines, where the mixture should have adequate flowability and stability for actual construction purposes.

The L-box test is best utilized in evaluating the passing and filling capacity of SCC in applications where the concrete has to travel through closely packed reinforcement without vibrational assistance from outside. Compared to other tests that are purely based on flowability, the L-box test puts more consideration on the continuity of the concrete's flow during passage through restrictions. This property is important in structural members such as columns, beams, and heavily reinforced walls, where obstructions can weaken the structure and cause defects like voids or honeycombing. Through the simulation of these conditions, the L-box test ensures that the SCC mix design is appropriate for the desired application, particularly in intricate structural members. In addition, the L-box test offers indirect information about the resistance of SCC to segregation.

If the mixture flows unevenly or accumulates behind the reinforcement, it may indicate inadequate cohesion or excessive segregation, leading to poor quality and reduced strength. The test can be complemented by visual observations of the concrete's flow pattern, surface finish, and aggregate distribution, which offer further insights into the mix's stability. With other new property tests such as the slump flow and V-funnel tests, the L-box test is crucial to ensuring that SCC not only flows but also maintains its uniformity, cohesion, and workability during the placing process, to satisfy the performance needs of today's construction.



L-BOX

V-FUNNEL TEST

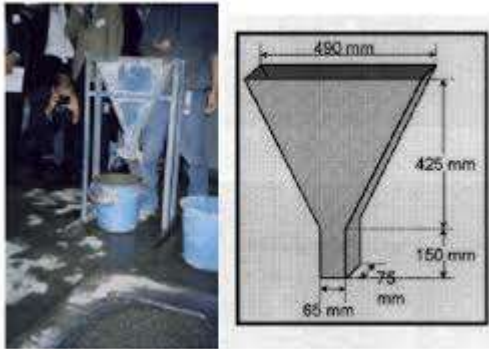
The V-funnel test is a standard method used to evaluate the flowability and viscosity of Self-Compacting Concrete (SCC) in its fresh state. This test provides a measure of the time it takes for the concrete to flow through a funnel-shaped apparatus, offering insights into its ability to pass through narrow spaces and maintain a consistent flow. Unlike the slump flow test, which primarily assesses

horizontal spread, the V-funnel test focuses on the vertical flow behaviour of SCC, making it a complementary tool for understanding the mix's overall performance.

The test procedure involves filling the V-shaped funnel with fresh SCC, allowing the concrete to settle for a few seconds, and then opening the bottom gate to let it flow out. The time taken for the entire volume of SCC to exit the funnel is recorded as the V-funnel flow time. This time typically ranges between 6 to 12 seconds for a well-designed SCC mix, according to EFNARC (European Federation of National Associations Representing Concrete) guidelines. A shorter flow time indicates a more fluid mix with low viscosity, while a longer time suggests a more viscous mixture, which may be beneficial in preventing segregation but could compromise flowability in complex formwork.

The V-funnel test is particularly effective in assessing the viscosity of SCC, which plays a critical role in determining its ability to flow smoothly without segregation. A highly viscous SCC mix may have a longer V-funnel flow time, indicating better resistance to segregation and bleeding, which is crucial for maintaining the homogeneity of the concrete during placement. However, excessive viscosity can reduce the mix's flowability, making it difficult to fill intricate formwork or pass through heavily reinforced sections. Therefore, achieving a balance between flowability and viscosity is essential for ensuring that SCC performs well in both fresh and hardened states.

In addition to measuring flow time, the V-funnel test can also provide qualitative information about the SCC mix, such as its cohesiveness and aggregate distribution. If the SCC flows out unevenly or if blockages occur during the test, it may indicate issues with the mix design, such as insufficient paste volume or improper aggregate grading. These observations can help identify potential adjustments to the water-to-cement ratio, superplasticizer dosage, or aggregate content to optimize the SCC's performance. When used in combination with other tests like the slump flow and L-box tests, the V-funnel test offers a comprehensive evaluation of SCC's fresh properties, ensuring it meets the stringent requirements for modern construction projects.



V-FUNNEL

T-50 TEST

The T50 test is a supplementary measure conducted alongside the slump flow test to assess the viscosity and flow rate of Self-Compacting Concrete (SCC). While the slump flow test evaluates the overall spread diameter of SCC, the T50 test specifically measures the time required for the concrete to spread to a diameter of 50 cm after the slump cone is lifted. This time, known as the T50 time, provides valuable information about the concrete's flow speed, cohesiveness, and resistance to segregation. It is a crucial parameter for ensuring that SCC can achieve the required flowability without being too fluid or too stiff.

Typically, a T50 time between 2 and 5 seconds is considered ideal for SCC, according to the EFNARC guidelines. A shorter T50 time indicates a more fluid mix with low viscosity, which is beneficial for applications requiring rapid flow and easy placement. However, overly fluid mixes may lead to segregation and uneven distribution of aggregates. Conversely, a longer T50 time suggests a more viscous mix, which offers better stability and segregation resistance but may require additional effort to achieve full compaction in intricate formwork or heavily reinforced structures.

The T50 test is particularly important in projects where the balance between flowability and stability is critical, such as in the construction of columns, beams, walls, and other structural elements with dense reinforcement. A mix with an appropriate T50 time ensures that SCC flows smoothly around obstacles without separating or causing voids. Additionally, the T50 test helps assess the effect of admixtures like superplasticizers or viscosity-modifying agents (VMAs) on the concrete's flow characteristics. By monitoring the T50 time, engineers can fine-tune the mix design to achieve optimal performance, ensuring the SCC meets both workability and durability requirements for modern construction.

Type of admixture	w/r or w/b	Slump (mm)	flow	L-box (H2/H1)	V-funnel (s)	T-50 (h2-h1) mm
	0.43	653-710		0.85-0.98	9.0-11	-

Fly ash		710-800	-	12-42	-
Silica Fume	0.28				
	0.33	705-745	0.85-0.95	7-12	0.8-0.9
	0.31	550-650	0.80-0.88	10.2 -12	-
GGBS	0.35	600-750	0.92-0.96	-	-
	0.44	680-720	-	-	8-14

Table 3. Fresh properties of mineral admixtures in SCC mixture

MECHANICAL PROPERTIES

Ordinary Portland Cement (OPC) of either 43 or 53 grade is used in this application. The aggregates are limited to a maximum size of 20mm, with congested reinforcement requiring sizes between 10mm and 12mm. It is essential to utilize well-graded aggregates that are either cubical or rounded in shape. The fine aggregates can be sourced from natural deposits or manufactured, provided they maintain a uniform grading. Additionally, any particle sizes smaller than 0.125mm are classified as fines. The water used in the mixture must meet the same quality standards as that required for reinforced concrete or pre-stressed concrete applications.

Cement is among the most basic of materials used in the building sector, being the main binding substance in concrete, mortar, and other structural contexts. The mechanical characteristics of cement are responsible for the strength, durability, and performance of concrete and cement-based structures. Such characteristics have a direct influence on the load-bearing capability, deformation resistance, and general stability of buildings, roads, bridges, and other construction projects.

The mechanical properties of cement are influenced by chemical composition, hydration process, curing conditions, and the presence of admixtures or supplementary materials such as fly ash, silica fume, or GGBS (Ground Granulated Blast Furnace Slag). These properties are important for engineers, architects, and construction professionals to design long-lasting and high-performance concrete structures.

SPLIT TENSILE STRENGTH TEST

The Split Tensile Strength Test is an indirect test to find the tensile strength of concrete since concrete is weak in tension. While compressive strength is comparatively high, the tensile strength of concrete is merely 10–15% of its compressive strength. It is necessary to measure this property for designing structures that can withstand bending, cracking, and shear forces.

This test is performed by testing a cylindrical concrete specimen for a uniform tensile stress in the direction of its diameter. This test complies with specifications like IS 5816:1999, ASTM C496, and BS 1881:117.

Concrete is used extensively in building construction because of its high compressive strength, but it is much weaker under tension. Because concrete structures tend to be subjected to tensile forces caused by bending, shrinkage, thermal gradients, and applied loads, their tensile strength must be established to ensure safety and longevity of the structure.

The Split Tensile Strength Test is an indirect test for assessing the tensile strength of concrete. It consists of fixing a cylindrical concrete specimen horizontally in a Compression Testing Machine (CTM) and subjecting it to a uniform load along its vertical diameter. This induces indirect tensile stress across the horizontal plane of the cylinder, which ultimately results in splitting failure.

Since testing the direct tensile strength of concrete is difficult owing to gripping difficulties with the specimen and the need to achieve uniform stress distribution, the split tensile strength test is a viable and reliable option. It finds extensive application in structural engineering to measure the crack resistance and durability of the concrete in roads, pavements, bridges, beams, and hydraulic structures.

The average tensile strength of regular concrete is between 2.5 MPa and 4.0 MPa, whereas high-strength concrete can have values between 5.0 MPa and 10.0 MPa. The outcome of this test is important in determining the capability of the concrete to resist tension-induced cracks, which can affect its lifespan and structural integrity greatly. Engineers utilize this information to develop reinforced concrete structures, making proper placement of the reinforcement to resist tensile stresses in structural elements like beams, slabs, and roads. The test is especially effective for evaluating the resistance of concrete pavement and bridge decks to cracks, where tensile stresses

resulting from traffic loads and temperature fluctuations are the general occurrence. The test is carried out using a cylindrical concrete sample, which is usually 150 mm in diameter and 300 mm in height, although 100 mm × 200 mm cylinders are utilized in certain situations. These samples are cast, suitably cured for 7 to 28 days, and then tested in a compression testing machine (CTM). In contrast to a direct tensile test, in which a concrete specimen is stretched apart, the split tensile test is applied with a compressive load down the length of the specimen, creating an indirect tensile stress perpendicular to the loading. This is done by positioning the cylinder horizontally between two loading strips, which distribute the force evenly along the length of the specimen.



SPLIT TENSILE STRENGTH TEST

Mix proportion %	Split tensile strength (7 days)	Split tensile strength (28 days)
MFA-0	1.08	1.74
MFA-10	1.23	1.89
MFA-20	1.35	2.01
MFA-30	1.47	2.08
MFA-40	1.30	1.92
MFA-50	1.27	1.82

Table 4. Split Tensile Strength

FLEXURAL STRENGTH TEST

Concrete is a basic building material characterized by high compressive strength but comparatively low tensile strength. In actual construction applications, concrete structures like beams, slabs, pavements, and bridges experience bending and flexural stresses from applied loads. The Flexural Strength Test is an important test utilized to measure the strength of concrete in resisting bending forces prior to failure.

Also known as the modulus of rupture (MOR) test, the test measures how effectively concrete resists tensile stress caused by bending. The test provides engineers with the information needed to design and build resistant structural components, so they do not crack or fail too early if they are subjected to flexural loads. This test is especially critical in pavement and bridge deck design, where flexural strength tends to be more demanding than compressive strength.

Concrete is mostly employed in structural components where bending happens often, i.e., beams, slabs, and roads. If the concrete does not have sufficient flexural strength, it can fail through cracking or excessive deflection.

The Flexural Strength Test, or the Modulus of Rupture (MOR) test, assesses the ability of concrete to resist bending stress. It is an indirect indication of concrete tensile strength because concrete has a weak nature in tension and is prone to cracking when placed under flexural loading. Testing involves subjecting a prism-shaped beam specimen to a bending force until it breaks. This is useful for determining the ultimate stress at which the concrete will fail, thereby allowing structures to remain long-lasting in any given loads.

For such applications as highway pavements, airfield runways, bridge decks, and industrial floors, flexural strength is usually more important than compressive strength. Concrete surfaces experiencing moving loads,

vehicle pressure, and environmental exposure must possess proper flexural capacity to avoid premature cracking and premature structural degradation. Flexural strength is directly controlled by the quality control of the concrete mix, reinforcement placement, and curing procedures, making it a key property in structural engineering.

Various international standards, such as ASTM C78, ASTM C293, IS 516, and BS 1881, define the testing procedure for flexural strength. The test results help engineers select the right cement mix proportions, aggregate type, and curing conditions to enhance the durability and performance of concrete structures. Understanding the factors affecting flexural strength enables the optimization of concrete mix designs, ultimately improving the longevity and safety of civil engineering projects.



FLEXURAL STRENGTH

Mix proportion %	Flexural strength (7 days)	Flexural strength (28 days)
MFA-0	2.14	3.06
MFA-10	2.87	4.19
MFA-20	3.56	5.01
MFA-30	4.38	5.95
MFA-40	4.17	5.20
MFA-50	3.92	4.82

Table 5. Flexure Strength

SULFATE ATTACK TEST

Concrete structures are often exposed to aggressive environmental conditions that can lead to deterioration over time. One of the most common and damaging durability issues in concrete is sulfate attack, which occurs when sulfate ions from external sources, such as groundwater, seawater, industrial waste, or contaminated soil, react with the hydrated cement compounds. This reaction can cause expansion, cracking, strength loss, and reduced durability of the concrete. In the case of Self-Compacting Concrete (SCC), which is widely used for its superior workability, flowability, and ease of placement, it is crucial to assess its resistance to sulfate attack to ensure long-term structural performance.

The Sulfate Attack Test is conducted to evaluate how SCC performs in sulfate-rich environments. Since SCC often contains supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast furnace slag (GGBS), and silica fume, its sulfate resistance can vary based on the mix design. The test simulates real-world exposure conditions by immersing SCC specimens in a sulfate solution and monitoring changes in properties such as expansion, mass loss, compressive strength, and surface deterioration over time.

Self-Compacting Concrete (SCC) is a highly flowable and non-segregating type of concrete that can fill formworks and pass through congested reinforcement without the need for mechanical vibration. Due to its advanced properties, SCC is widely used in complex structural elements, precast concrete, and high-performance construction. However, like all types of concrete, SCC is susceptible to sulfate attack, which can lead to deterioration over time, particularly in marine environments, sewage systems, and sulfate-rich soils.

The Sulfate Attack Test is conducted to evaluate the durability and resistance of SCC against sulfate-rich environments. When concrete is exposed to sulfate ions (SO_4^{2-}) from groundwater, seawater, or industrial effluents, chemical reactions occur with hydrated cement compounds, leading to expansion, cracking, loss of strength, and disintegration. The test helps engineers determine the long-term stability and performance of SCC under sulfate exposure.



SULFATE ATTACK

Mix proportion (%)	Average reduction in wt. 28 days	Average reduction in wt. 56 days	Average reduction in wt. 90days
MFA-0	2.14	2.8	3.35
MFA-10	2.09	2.75	2.98
MFA-20	1.76	2.19	2.74
MFA-30	1.09	2.56	2.56
MFA-40	2.20	2.82	2.98

Table 6. Sulfate Attack Test

CONCLUSION

The study on the chemical durability characteristics of minerals and blended sustainable Self-Compacting Concrete (SCC) using a blend of admixtures contributes to understanding the long-term durability of SCC in chemically aggressive conditions. The use of supplementary cementitious materials (SCMs) like fly ash, ground granulated blast furnace slag (GGBS), silica fume, and metakaolin in this research has proven that SCC can be made more durable while ensuring environmental sustainability.

Important observations show that addition of mineral admixtures enhances resistance to chloride penetration, sulfate attack, carbonation depth, and alkali-silica reaction (ASR) susceptibility, depending on the type and content of SCMs. X-ray diffraction (XRD), scanning electron microscopy (SEM), and mercury intrusion porosimetry (MIP) advanced microstructural analysis verified that the optimized SCC mixes have tighter pore structures and lower permeability, which help to enhance durability.

This study points out that through the proper selection of suitable mineral and chemical admixtures, SCC can be engineered to resist extreme environmental conditions, lower its carbon footprint, and prolong the lifespan of structures. The research lays the groundwork for more studies and real-world applications in the construction sector, highlighting the importance of green concrete solutions that are durable, strong, and environmentally friendly.

Future research will be directed toward long-term field performance investigations and mix design optimization for particular environmental conditions to assure the wider use of sustainable SCC in contemporary construction.

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