

Performance Evaluation of Sodium Trimetaphosphate (STMP) Modified Gum Arabic as an Agricultural-based Superplasticizer on Fresh and Hardened Properties of Self-Compacting Concrete

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ABSTRACT

This study evaluates the performance of Sodium Trimetaphosphate (STMP) modified Gum Arabic (MGA) as a sustainable bio-admixture for Self-Compacting Concrete (SCC). comparing its fresh, rheological, and mechanical properties against raw Gum Arabic (GA) and a commercial synthetic superplasticizer (SP). Under standardized laboratory procedures, SCC mixes were formulated using Portland Cement (CEM II/A-LL, 42.5) with incremental admixture dosages (0.5%, 1.0%, and 1.5% by binder weight) at a constant water-to-binder ratio of 0.40. Fresh properties were evaluated using Abram's slump flow, V-funnel flow time, and L-box blocking ratio (h_2/h_1). Rheological yield stress was derived via an indirect slump-flow methodology, Mechanical strength was assessed using displacement-controlled compression and tensile tests at 28 days, supplemented by X-ray Diffraction (XRD) for mineralogical phase analysis. Experimental results established 1.0% concentration as the optimal saturation threshold across all formulations. At this dosage, 1.0% MGA achieved a slump flow spread of 645 mm, which is 3.73% lower than both 1.0% GA (670 mm) and 1.0% SP (670 mm), yet fully satisfying EFNARC (2005) deformability criteria. In viscosity assessments, MGA demonstrated superior discharge efficiency, recording a V-funnel time of (20.32 s) a 63.71% reduction compared to GA (56.00 s) and a 32.27% reduction compared to SP (30.00 s). Passing ability tests yielded an L-box ratio of 0.91 for MGA, which is 1.09% lower than GA (0.92) and 3.19% lower than SP (0.94), well above the 0.80 non-blocking threshold. Rheological modelling revealed that MGA significantly reduced internal shear resistance, achieving a yield stress of 57.94 Pa and 8.44% reduction compared to GA (63.28 Pa) and a 3.16% reduction compared to SP (59.83 Pa). In hardened state testing, 1.0% MGA attained a 28-day compressive strength of (40.67 N/mm²) (Grade C32/40, representing a 0.12% increase over GA (40.62 N/mm²) and a 0.39% increase over SP (40.51 N/mm²). MGA also achieved a 28-day split tensile strength of (4.59 N/mm²), XRD patterns confirmed the formation of dense Calcium Silicate Hydrate (C-S-H) gel without adverse phase shifts. STMP modification successfully enhances the anionic charge density of raw GA, establishing MGA as a viable high-performance replacement for synthetic superplasticizers.

Keywords: Sodium Trimetaphosphate (STMP), Modified Gum Arabic, Agricultural-based Admixture, Rheology and Self-compacting Concrete (SCC).

INTRODUCTION

Concrete is the world's most widely used construction material, sustained by its cost effectiveness and raw material accessibility. As noted by (Abhijeet 2023), the evolution of concrete technology is dictated by the critical mandates of increasing construction velocity and enhancing structural durability. This evolution has driven the development of "Special Concretes," particularly Self-Compacting Concrete (SCC). Unlike

Normal Concrete (NC), SCC is defined by its ability to flow autonomously under its own mass to fill intricate formwork and congested reinforcement without mechanical vibration, a paradigm shift noted by (Athman et. al. 2018). As highlighted by Mohamad et al. (2016), eliminating mechanical compaction significantly improves both the quality of the finished structure, the safety and ergonomics of the construction environment. Furthermore, (Krishna et al. 2012) emphasize that SCC's rheological properties ensure homogeneity and prevent internal blockage, resulting in microstructures that often exceed the durability metrics of traditionally vibrated concrete. Despite these advantages, the production of SCC requires a precise balance between high deformability and segregation resistance, usually achieved through synthetic, petroleum-based superplasticizers. However, these chemicals present significant environmental and cost challenges. While raw natural polymers like Gum Arabic (GA) offer a sustainable alternative their raw form often lacks the anionic charge density required to provide sufficient electrostatic repulsion and steric hindrance between cement particles. To address these limitations, a bio-based superplasticizer was developed through the chemical modification of Gum Arabic with STMP. The core of the problem lies in determining the precise impact of this modified admixture on the rheological constants of the concrete. Specifically, the newly developed superplasticizer must be tested to define its optimal content, saturation point, and its ability to modulate yield stress and plastic viscosity. Failure to accurately calibrate these properties may hinder the fresh SCC from behaving as a true Bingham Liquid, leading to issues such as blockage during passing or structural instability in the hardened state. they often lack the necessary anionic charge density to provide effective electrostatic repulsion between cement particles (Salahaldein & Abdelnaser, 2022). To address these limitations, researchers have developed an agricultural-based superplasticizer through the chemical modification of Gum Arabic with Sodium Trimetaphosphate (STMP). As explored by Salahaldein & Abdelnaser (2022), concrete has evolved into a highly engineered material, and determining the precise impact of such modifications on rheological constants such as yield stress and plastic viscosity is vital. Failure to calibrate these properties could prevent the SCC from behaving as a true Bingham Liquid, leading to blockage or structural instability. Consequently, there is an urgent need to evaluate and certify STMP modified Gum Arabic in accordance with industry standards, such as (ASTM D 1045-14), to ensure its technical viability for industrial applications.

LITERATURE REVIEW

Admixtures are specialized substances, distinct from water, cement, and aggregates, integrated into concrete to regulate setting times, improve workability, and enhance overall durability (EFNARC, 2005). Among these, Gum Arabic (GA) derived primarily from the resilient Acacia Senegal tree which is a vital industrial crop in Nigeria's Sahelian "gum belt" (Anderson, 1978; NFTA, 1991; Bababe, 2002). Known as "Desert Gold," this polysaccharide supports approximately 3 million Nigerians and is widely utilized in the food, pharmaceutical, and land management sectors for its unique emulsifying properties (Okatahi et al., 2017; Umar, 2023). In the context of SCC, raw GA provides enhanced cohesion and effective water reduction; however, its inherent high viscosity and insufficient charge density limit its performance compared to synthetic superplasticizers (Mbugua et al., 2016). Furthermore, Mbugua (2016) highlight the urgent need for natural, cost-effective admixtures tailored to arid African climates, where high temperatures often lead to rapid workability loss and improper site practices, such as excessive water addition, which weaken structural integrity. The rationale for modifying raw Gum Arabic (GA) for use as a superplasticizer centre on overcoming its inherent limitations in rheological control. While raw GA functions as an effective thickener and dispersing aid, its high viscosity can unintentionally reduce the compressive strength of concrete and fails to match the precision of synthetic admixtures, particularly in hot climates where rapid workability loss often leads to detrimental on-site water addition (Mbugua et al., 2016). To address these issues, the material undergoes a multi-stage chemical synthesis involving homogenization, cross-linking with STMP, pH calibration, and purification to enhance its anionic charge density and molecular stability (Francisco et al., 2014; Zakka et. al., 2019). This controlled transformation is critical to optimize the polymer's ability to modulate yield stress and plastic viscosity, ensuring the resulting bio superplasticizer can achieve the high fluidity and structural stability required for SCC without compromising durability (Francisco et. al., 2014).

The performance of SCC is primarily optimized through the use of superplasticizers, which significantly enhance fluidity and workability. As noted by (Zakka et. al., 2015) contemporary concrete formulations almost invariably include additives whether mineral or synthetic to regulate setting times and reduce water demand while bolstering both fresh and hardened state characteristics. The application of high range water reducers (superplasticizers) has shifted from a specialty technique to a standard industry practice (Zakka et al., 2019). Aligning with these advancements, this research constitutes a strategic investigation into the efficacy of STMP modified Gum Arabic as a bio-based superplasticizer, evaluating its specific influence on the rheological and mechanical performance of SCC. Consequently, there is an urgent need to evaluate and certify the performance of STMP modified Gum Arabic in accordance with industry standards, such as (ASTM D 1045-2014), to ensure its technical viability and readiness for industrial use.

MATERIALS AND METHODS

This section presents a brief description of the materials used for the experimental work, along with tests conducted on the materials and the concrete in its fresh state as well as hardened state.

Materials

Cement : Portland Cement (PC), CEM II/A-LL, 42.5 (3X from Dangote Cement) conforming to (BS EN 197-5:2021) standard, served as the primary binder in this experiment.

Aggregates: Locally sourced fine and coarse aggregates were utilized in compliance with (BS EN 12620:2013 and BS 8500:2023) specifications. Key physical properties, including specific gravity, Bulk density, moisture content and particle size distribution, were evaluated to ensure conformity with SCC mix design requirements. The maximum aggregate size used in this study was 10.1mm in line with (EFNARC 2005).

Water: All SCC specimens were mixed and cured using potable water obtained from the tap stationed for the concrete lab Department of Building FUT Minna. guaranteeing uniform quality and adherence to (BS EN 1008:2002) requirements

Agricultural Base Polymer Superplasticizer

Locally sourced (Plate 1) and modified Gum Arabic (Plate 2) was utilized as the superplasticizer to achieve the high workability required for SCC.

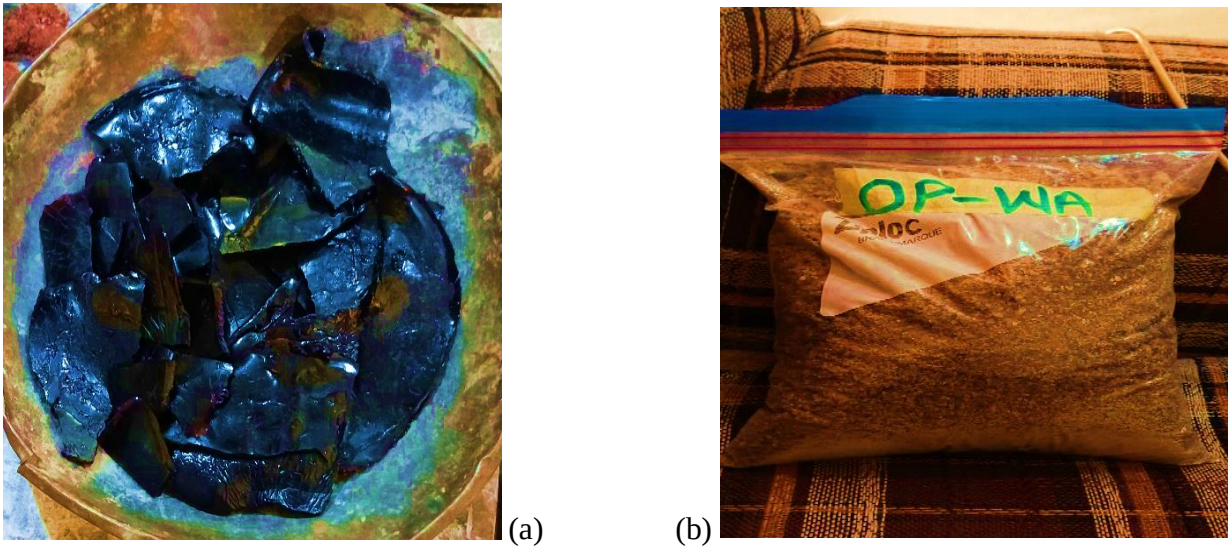


Plate 1: Gum Arabic Samples (a). Raw; (b). Modified

The dosages were adjusted following the (EFNARC 2005) guideline to maximize flowability without causing segregation. A commercial synthetic superplasticiser (SIKA Visconcrete, a polycarboxylic ether (PCE)) and the raw Gum Arabic (GA) were however adopted as control against which performance of the Modified Gum Arabic was measured.

METHODS

Characterization of Constituent Materials

Aggregate suitability for SCC was assessed according to (BE EN 1097-6:2022 and BS EN 206-9:2010) standards by determining physical properties like specific gravity, bulk density, and particle size distribution. Through standardized sieve analysis, key indices including the coefficient of curvature (C_c), uniformity coefficient (C_u), and fineness modulus (FM) are derived to characterize gradation. These parameters are essential for evaluating how aggregate structure influences the overall mechanical performance and flow characteristics of the concrete. Details of the properties of constituent's materials are presented in the results and discussion session.

Chemical Modification of Gum Arabic

The crosslinking of Gum Arabic using sodium trimetaphosphate (STMP) was carried out using the method reported by Ribeiro et al., (2015) with some slight modifications. Gum Arabic solutions (20% w/v) were prepared using distilled water. The solutions were stirred and homogenised using a high-speed homogenizer at 1000 rpm for 30 minutes. Varying STMP concentrations (3%, 6%, and 9%) were added to the solutions, stirred and their pH adjusted (9, 11 and 13) using 2 mol/dm³ sodium hydroxide (NaOH). The solutions were then stirred in a water bath at controlled temperatures (20°C, 30°C, and 40°C) and reaction times (2, 4, and 6 hr). Upon completion of each reaction time, the pH of the GA mixtures were calibrated to a neutral pH of 7 using 1mol/dm³ sulfuric acid (H₂SO₄). Any uncrosslinked material was removed through centrifugation, followed by washing with a 1:1 solution of ethanol and acetone. The crosslinked material was then dried, pulverised, and stored in airtight plastic bags inside a desiccator to prevent any contact with moisture. (Lafia-Araga et al., 2025 & Francisco et al., 2014)

Mix Proportioning

Following EFNARC (2005) recommendations, SCC mix proportions were optimized for workability, stability, and strength. Experimental mixes utilized Modified Gum Arabic (MGA) at incremental 0.5% dosages by weight of cement, and compared against control specimens (GA and commercial SP). The

primary SCC mix comprised 25.2 kg cement, 35.76 kg fine aggregate, 34.32 kg coarse aggregate, and 7.98 kg water. Additionally, saturation point determination utilized 1.3 kg cement and 0.558 kg water. Detailed mix proportions and water-to-cement ratios are documented in Table 1.

Table 1: SCC Mix Proportions

S/N	Mix ID	Types of Paste	Total Binder kg/m ³	Fine Agg. Kg/m ³	Coarse Agg. Kg/m ³	Water Kg/m ³	SP G	W/B Ratio
1	0.5%SP	Control	525	745	715	210	1.41	0.4
2	1.0%SP	Control	525	745	715	210	2.82	0.4
3	1.5%SP	Control	525	745	715	210	4.23	0.4
4	0.5% GA	Unary	525	745	715	210	1.41	0.4
5	1.0% GA	Unary	525	745	715	210	2.82	0.4
6	1.5% GA	Unary	525	745	715	210	4.23	0.4
7	0.5% MGA	Unary	525	745	715	210	1.41	0.4
8	1.0% MGA	Unary	525	745	715	210	2.82	0.4
9	1.5% MGA	Unary	525	745	715	210	4.23	0.4

Fresh Properties of SCC

Slump Flow Test

To evaluate the filling ability and homogeneity of SCC in accordance with BS EN 12350-8:2010 and EFNARC (2005) standards. The procedure involves filling a standard Abram's cone with fresh concrete on a levelled, dampened base plate and lifting it vertically to allow the mix to flow freely under its own weight without mechanical vibration. The resulting spread is determined by averaging two perpendicular diameters of the concrete spread (EFNARC 2005).

Passing Ability Test

The L-Box test, conducted in accordance to (BS EN 12350-10:2010 and EFNARC (2005) guidelines, the apparatus consisting of a 600 mm high x 200 mm wide x 100 mm deep vertical hopper connected to a 700 mm long x 200 mm wide x 150 mm high horizontal trough was placed on a firm, levelled surface, internal surfaces were moisten all with a damp sponge, the vertical sliding gate was closed, freshly mixed SCC sample (14 L) was continuously poured into the vertical hopper until full without rodding, tamping, or mechanical vibration before striking off excess concrete level with the top rim. After allowing the sample to rest undisturbed for 30 ± 10 seconds, the sliding gate was then smoothly and rapidly raised in a single upward motion to allow the concrete to flow through the reinforcement grid into the 700 mm horizontal trough. Once all movement completely ceases, the vertical depth h_1 was measured and the final flow height h_2 at three points across the end wall of the horizontal trough, and average each set of readings to compute the passing ability blocking ratio $CB = h_2 / h_1$, where a value >0.80 indicates satisfactory passing ability in accordance with EFNARC and BS EN 12350-10 guidelines.

Viscosity Test

The V-funnel test, conducted per BS EN 12350-9:2010 and EFNARC (2005) guidelines, To determine the relative discharge flow time (t_v) of the fresh Self-Compacting Concrete (SCC) using a standard metallic V-funnel apparatus in accordance with BS EN 12350-9 / EFNARC guidelines. Using a Standard Metallic V-Funnel with top opening dimensions 490 mm x 65 mm and Bottom discharge orifice 65 mm x 75 mm having total height (H) 575 mm (425 mm trapezoidal section + 150 mm straight neck) Total fluid volume capacity (V-funnel) 10 liters (0.010 m^3), Base Frame and Catch Container; Rigid horizontal support stand with quick-release bottom sliding gate. Fresh Concrete Density Equipment Calibrated rigid container (V-bucket = 0.005 m^3), weighing balance (precision $\pm 1 \text{ g}$), strike-off bar. Auxiliary equipment included digital stopwatch (precision $\pm 0.1 \text{ s}$), damp sponges, sampling scoop, straight edge/trowel. Apparatus was Cleaned the interior surfaces of the V-funnel and moisten thoroughly with a damp sponge. To ensure the sliding trapdoor at the bottom orifice is clean, the orifice was fully closed, and latched. V-funnel was placed and secured on its rigid support stand, ensuring it is level and stable. The catch container was Positioned directly under the discharge orifice. Immediately after mixing, fresh SCC was scoop into the funnel in one continuous pour until filled to the top rim without rodding or vibrating. The top edge was then strike off excess concrete level using straight edge. The concrete was allowed to rest undisturbed in the funnel for 10 ± 2 seconds. Rapidly the bottom sliding trapdoor was open and the digital stopwatch Start at the exact instant the trapdoor opens. The funnel was carefully observed down vertically through the top opening of the funnel. the timer was stopped at the precise instant light becomes visible through the bottom discharge orifice (indicating the funnel has completely emptied). The time was recorded the elapsed time to the nearest 0.1second as the V-funnel flow time (t_v)

Yield Stress Test

This study determines SCC yield stress through an indirect slump-flow methodology following (ASTM C1611:2018), based on the rheological principles established by (Murata 1984 and Roussel & Coussot 2005). By measuring the final spread diameter (D_{flow}) and factoring in material density and cone geometry, the method provides a practical correlation between field deformability and laboratory-derived yield stress. Additional Pereira et.al, (2022) developed empirical formulas to calculate the yield stress (τ_0) of yield stress fluids (such as cement paste or concrete) based on the results of the slump test and slump flow (spread) test. These formulas are based on a 3D theoretical analysis of the flow and represent a significant improvement over earlier 1D models, particularly for high yield stress materials.

$$\tau_0 = \frac{7.5pgv^2}{8\pi 2R^5} \quad \text{Equ. (1)}$$

where:

τ_0 = Yield stress (Pa)

P = Density of the material (kg/m^3)

g = Acceleration due to gravity (9.81 m/s^2)

V= Volume of the slump cone (0.00557 m^3) for a standard Abrams cone)

R = Final spread radius (Average Flow/Density to convert mm to meters)

Hardened Properties of SCC

Mechanical Properties

Compressive Strength evaluated on 100 x 100 x 100 mm cube specimens in accordance with BS EN 12390-3 / ASTM C39. While splitting tensile, and flexural strengths was evaluated on 100 x 300 mm cylinder and

100 x 100 x 500 mm beam respectively, specimens were cured in water tanks at $23 \pm 2^\circ\text{C}$ until testing at 7, 14, 21 and 28 days, using a 2000 KN testing machine in accordance with and BS EN 12390-6:2021) standards, cylindrical and Beam specimens were tested across various curing ages using displacement-controlled loading to ensure consistent data acquisition.

X-ray Diffraction Test

The X-Ray Diffraction (XRD) analysis was performed using a Rigaku MiniFlex 600 Diffractometer (Plate XIV) to determine the crystallographic structure and phase composition of the materials, which is vital for confirming the pozzolanic activity and mineralogical compatibility of Modified Gum Arabic (MGA) within the concrete matrix. The procedure involved grinding the sample into a fine, homogeneous powder and mounting it into a flat holder to ensure a smooth interface for the incident X-rays, set at an operating tension of 45kV and a current of 40mA. Using a Theta-Theta reflection-transmission configuration, the sample was scanned across a 2θ range of 4° to 75° with a precise step size of 0.026° , allowing the detector to record the intensity of diffracted rays resulting from specific d-spacings within the mineral lattice. The resulting diffraction patterns were processed by measuring peak positions at 80% height and comparing relative intensities against standard databases like NIST and PubChem. For Self-Compacting Concrete (SCC), this analysis is essential as it identifies the formation of strength-enhancing phases, such as Calcium Silicate Hydrate (C-S-H), and ensures that the chemical structure of the bio-admixtures effectively supports the desired rheological and mechanical performance without adverse mineralogical shifts.

Multi-Criteria Decision Analysis (MCDA)

To eliminate single parameter bias and determine the overall optimal dosage of Sodium Trimetaphosphate modified Gum Arabic (STMP MGA) relative to raw Gum Arabic (GA) and a commercial synthetic superplasticizer (SP), a weighted linear combination Multi-Criteria Decision Analysis (MCDA) model was applied across Fresh properties, Slump Flow (C5), V-Funnel Time (C3), and L-Box Passing Ratio (C2) and hardened mechanical properties 28-day Compressive Strength (C1) and 28-day Split Tensile Strength (C4) were evaluated. Weightings ($\sum W_j = 1.00$) were assigned based on structural and EFNARC priority guidelines thresholds.

Experimental parameter values were transformed into non-dimensional normalized scores (N_{ij} [0, 1]). For beneficial performance indices (C1, C2, C4, C5), linear max-min normalization was applied using Equation (2)

$$N_{ij} = \frac{X_{ij} - X_{\min}}{(X_{\max}) - (X_{\min})} \quad \text{Equ (2)}$$

While for non-beneficial criteria (C3), where lower values signify superior performance, normalization was derived using Equation (3)

$$N_{ij} = \frac{X_{\max} - X_{ij}}{(X_{\max}) - (X_{\min})} \quad \text{Equ (3)}$$

And the composite performance score (S_i) for each mix batch was computed via Equation (4)

$$S_i = \sum_{j=1}^m W_j \cdot N_{ij} \quad \text{Equ (5)}$$

RESULTS AND DISCUSSION

The results obtained from the laboratory experiment are presented in the following section with proper discussion of the observed phenomena.

Materials Characterization

The physical properties of constituent materials are presented in Table 2. It revealed the materials specific gravity values of 3.15 for PC, 2.40 for the natural sand used as fine aggregate and 2.66 for granite used as coarse aggregate. These values reveal typical ranges for the respective materials.

Table 2: Physical Properties of Constituent Materials

Materials	Specific Gravity G _s	Bulk Density Uncompact	Moisture content.
Cement	3.15	1400.0	NA
Fine Aggregate	2.40	1092.8	3.08
Coarse Aggregate	2.66	1302.64	NA

NB: N/A implies not applicable.

The particle size distribution curve of the aggregates is presented in in Figure 1 while Table 4 gave the summary of the sieves analysis confirming the suitability of the materials for use in SCC production.

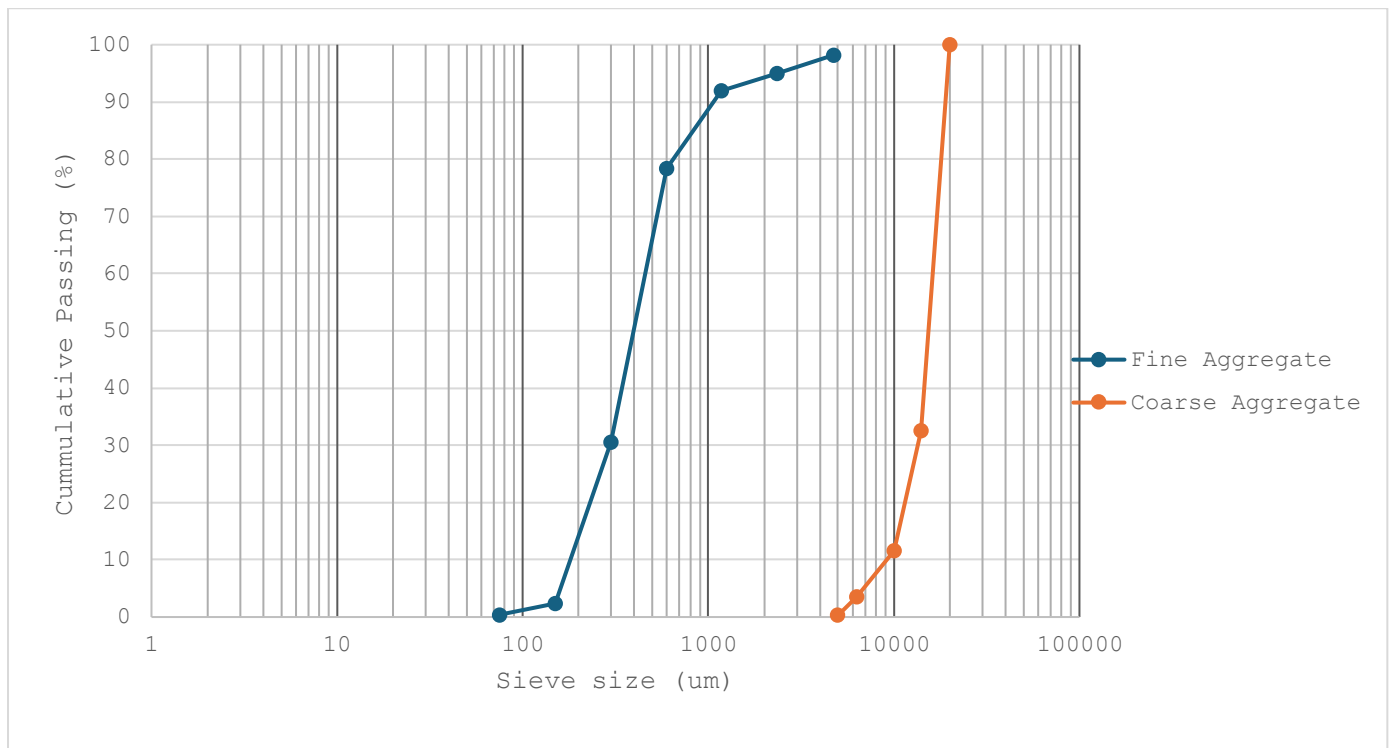


Figure 1: Particle Size Distribution of Aggregates

Table 3: Summary of Sieve Analysis

	D ₁₀	D ₃₀	D ₆₀	C _u	C _c	FM
Sieved Sand	0.10	0.28	0.75	7.5	1.05	2.83
Granite	6.3	8.0	10.1	1.60	1.01	NA

The fine aggregate exhibited an effective size D_{10} of 0.10mm, D_{30} of 0.28mm and D_{60} of 0.75mm which represent the effective size or diameter corresponding to 10%, 30% and 60% passing the respective sieves. The values were substituted into standard equation for determining the values of Coefficient of Curvature (C_c), Uniformity Coefficient (C_u) and FM respectively. in which C_u of 7.5 was obtained, which classifies the sand as well-graded according to standard geotechnical criteria ($C_u > 4$). A well-graded fine aggregate is advantageous for SCC as it ensures a high packing density, thereby reducing the volume of cement paste required to fill inter-granular voids. The C_c was determined to be 1.05. which is within the ideal range (1 to 3), the values suggest sufficient fineness to contribute to the mix's plastic viscosity and segregation resistance, the fineness modulus of 2.83 also confirm that the fine aggregate falls into the ideal well graded medium sand which signifies an optimal mean particle size that guarantees excellent workability, good compressive strength and high density in concrete matures. The coarse aggregate displayed a D_{10} of 6.3mm, D_{30} of 8.0mm and a D_{60} of 10.1mm, resulting in a C_u of 1.60. This relatively low uniformity coefficient is typical for crushed stone used in high-performance mixes, where a restricted maximum size is preferred to enhance passing ability. However, the calculated C_c of 1.05, indicating a well-graded distribution within the coarse fraction itself suggests that the coarse aggregate has intermediate particle sizes, a characteristic that must be compensated for by increasing the sand to total aggregate ratio to ensure a homogeneous mortar phase.

From the perspective of SCC rheology, these curves and the resulting combined grading are critical. The small D_{60} of the coarse aggregate (10.1 mm) is specifically beneficial for the passing ability of the concrete. By limiting the maximum particle size, the risk of "blocking" where larger particles bridge across reinforcement bars and impede flow is significantly reduced. Furthermore, the abundance of fines in the sand (indicated by the 22% passing the 0.3 mm mark) provides the necessary fine material to the concrete, required to prevent the heavier coarse aggregates from sinking during the flow process.

Fresh Properties of SCC

Workability and Dispersion Kinetics

The primary distinction of SCC lies in its exceptional rheological behaviour in the plastic state. Unlike conventional vibrated concrete, fresh SCC must exhibit a delicate balance of high fluidity and high stability. These properties are typically achieved through an optimized particle packing density, a high volume of mineral fillers, and the strategic use of Superplasticizers (SP) (Salahaldein & Abdelnaser, 2022). In this study, the fresh properties were assessed to determine the influence of various admixtures specifically natural Gum Arabic (GA), Modified Gum Arabic (MGA), and a synthetic Superplasticizer (SP) on the workability and dispersion kinetics of the mix. Table 4 present the results for slump flow, passing ability, and filing ability and viscosity.

Table 4: Slump Flow, Passing-ability and Filling-ability of SCC

Sample ID	Aver. Flowability (mm)	V-Funnel (Sec)	L-Box Passing Ratio (h_2/h_1)
0.5% SP	655	24.28	0.92
1.0%SP	670	30	0.94
1.5%SP	620	1.01	0.88
0.5%GA	360	No Flow	NF
1.0%GA	670	56	0.92
1.5%GA	540	5.27	0.8

0.5%MGA	655	40	0.96
1.0%MGA	645	20.32	0.91
1.5%MGA	657	20.5	0.81

At a low dosage of 0.5%, unmodified GA failed to achieve self-compaction, yielding a slump flow of only 360 mm (a 45.0% deficit from the lower limit of (EFNARC 2005) requirements. In contrast, 0.5% MGA recorded 655 mm, representing an 81.9% increase in flowability over 0.5% GA. Furthermore, while increasing unmodified GA to 1.5% reduced the flowability to 540 mm due to excessive viscosity, MGA maintained stable flowability across all dosage rates (655 mm at 0.5%, 645 mm at 1.0%, and 657 mm at 1.5%). At 1.5% dosage, MGA achieved 21.7% higher flowability than GA. Similarly, MGA when compared with synthetic SP exhibits dosage sensitivity; increasing SP from 1.0% to 1.5% caused a 7.5% drop in flowability (670 mm to 620 mm), MGA exhibited far superior dosage stability, varying by less than 1.8% across all three tested dosages (645 - 657 mm). At 1.5% dosage, MGA provided 6.0% higher flowability than SP. While GA at 0.5%, suffered total blockage (No Flow) due to insufficient plasticizing effect. At 1.0% GA, the mix became overly viscous, resulting in an exceptionally high V-funnel time of 56 seconds. 1.0% MGA drastically reduced the discharge time to 20.32 seconds a 63.7% reduction in viscosity/flow time, while MGA compared with synthetic SP at 1.5% dosage shows that SP exhibited extreme fluidity/instability with a V-funnel time of 1.01s, which falls below the (EFNARC 2005) threshold of 6s and indicates severe segregation risk and loss of paste cohesion. Conversely, 1.5% MGA maintained a balanced viscosity profile (20.50s), staying well within the EFNARC VF₂ viscosity class (25s).

According to the performance criteria established for self-compacting concrete (EFNARC, 2005), an h_2/h_1 blocking ratio ≥ 0.80 is the standard threshold for ensuring adequate passing ability. As observed from Table 4, the dosages have influence on flowability of the SCCs. At 0.5% dosage, GA mix exhibited a total loss of flowability, whereas the MGA and SP formulations achieved ratios of 0.96 and 0.92, respectively. At 1.0% dosage satisfied the criteria. In specifics, MGA reached a ratio of 0.91, followed by SP at 0.94 and GA at 0.92. Increasing the dosage to 1.5% yielded diminishing returns across all the samples.

Yield Stress

Table 5 and Figure 2 reveals that MGA significantly improves SCC rheology compared to raw GA, reducing yield stress from a prohibitive range exhibited by GA to a stable range at another dosage level.

Table 5: Yield Stress Analysis of SCC Mixes

Sample ID	Aver. Flow (mm)	Density kg/m ³	Radius R (m)	Acceleration due to gravity (g)	V ² (m ³)	π^2	Yield Stress (Pa)
0.5%SP	655	2250.00	0.29	9.81	0.00557	9.87	31.10
1.0%SP	670	2557.00	0.26	9.81	0.00557	9.87	59.83
1.5%SP	620	2524.00	0.25	9.81	0.00557	9.87	81.57
0.5%GA	360	2440.00	0.15	9.81	0.00557	9.87	1008.71
1.0%GA	670	2581.00	0.26	9.81	0.00557	9.87	63.28
1.5%GA	540	2512.00	0.21	9.81	0.00557	9.87	158.16
0.5%MGA	655	2472.00	0.26	9.81	0.00557	9.87	54.70

1.0%MGA	645	2464.00	0.26	9.81	0.00557	9.87	57.94
1.5%MGA	657	2407.00	0.27	9.81	0.00557	9.87	45.92

Figure 2: Yield Stress Results for the different Admixtures

The comparative analysis of the rheological properties reveals that MGA functions as a significantly more effective and stable bio-admixture than raw GA for SCC. While the raw GA samples exhibited erratic yield stress values, including an excessively high peak of 1008.71 Pa at a 0.5% concentration which would severely inhibit flow, the MGA samples maintained a consistently low and predictable yield stress range between 45.92 Pa and 57.94 Pa. Consequently, MGA demonstrates superior potential as a sustainable alternative, ensuring the necessary deformability and low initiation stress required for high-quality SCC applications.

Hardened Properties of SCC

Compressive Strength

Figure 3 present an illustration of Compressive strength analysis, with all formulations meeting Grade C32/40 structural standards. A 1.0% MGA dosage proved optimal, achieving a peak 28-day compressive strength of 40.67 N/mm², while following standard logarithmic growth patterns. Low standard deviations validate the structural reliability and experimental consistency of these bio-admixtures. All samples achieved a compressive strength range between 26.00 N/mm² and 26.87 N/mm² by 7 days' age. The 1.0% SP based mix yielded the highest early strength at 7 days (26.87 N/mm²), closely followed by the 1.0% MGA based mix (26.70 N/mm²). By the 14-day mark, the mixes reached approximately 75-80% of their final 28-day target strength, with values ranging from 29.60 N/mm² to 32.49 N/mm². Notably, the 0.5% SP and 1.0% GA mixes shared the highest 14-day strength of 32.49 N/mm². The 28-day compressive strength is the primary benchmark for structural design and compliance with international standards therefore the 1.0% MGA mix achieved the highest overall compressive strength of 40.67 N/mm² at 28 days. This is followed closely by 1.0% GA (40.62 N/mm²) and 1.0% SP (40.51 N/mm²).

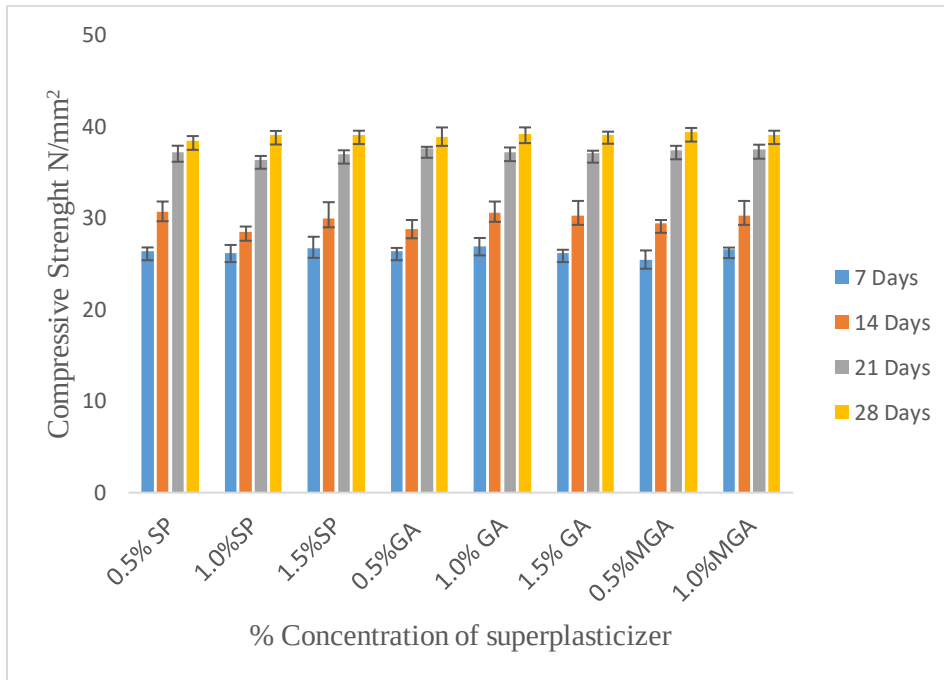


Figure 3: Compressive Strength of SCC

Across all three additives (SP, GA, and MGA), a 1.0% concentration consistently appears to be the "Optimum Dose," producing higher 28-day strengths than both the lower (0.5%) and higher (1.5%) dosages. The standard deviation remained low across most samples, particularly for the 1.0% MGA mix at 28-days (0.15), indicating high consistency in the experimental batching and testing process.

The achieved 28-day strengths (ranging from 38.21 to 40.67 N/mm²) classify these SCC mixes as Grade C32/40 concrete and fit the design strength of 40 N/mm². According to BS EN 206:2016, this grade is suitable for structural reinforced concrete in various environmental exposure classes, including foundations and reinforced concrete slabs. The standard deviations recorded (mostly < 1.0) fall within the "Good" to "Excellent" control category for laboratory prepared concrete in consonance with (ASTM C39, 2021) guidelines. Generally, it implies that the Modified Gum Arabic (MGA) does not affect strength development of SCC when compared with GA and SP results. confirming the reliability of the bio-admixtures (GA and MGA) as stable alternatives to GA and conventional synthetic SP.

Tensile Strengths

Figure 4 present the numeric and graphical comparative analysis of flexural and split tensile strengths. These results offer a comprehensive view of the concrete's ability to resist cracking and bending.

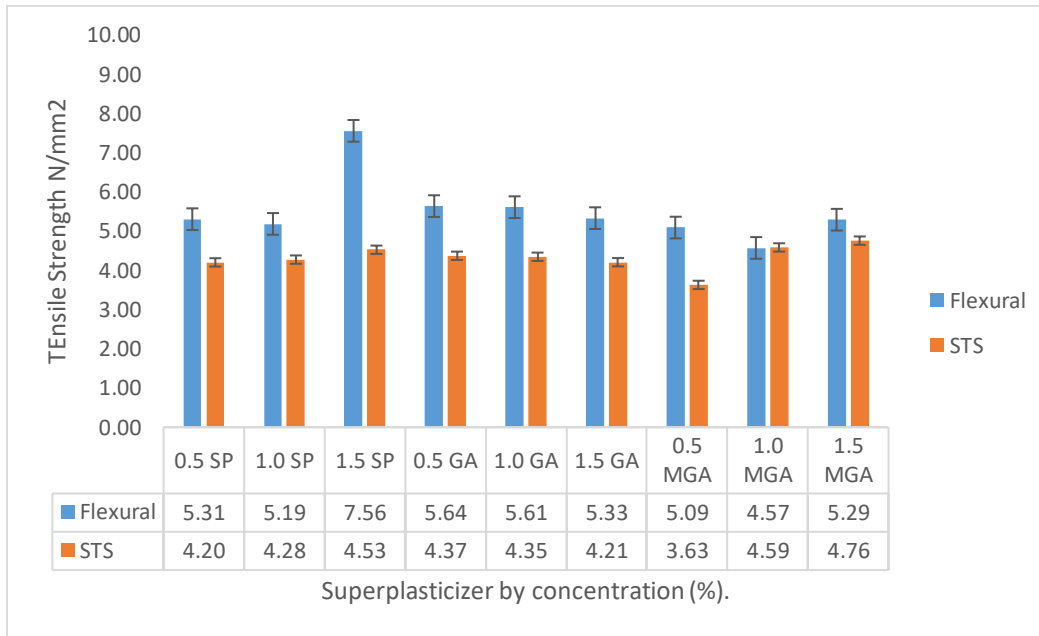


Figure 4: Tensile Strengths of SCC

The SCC samples from raw GA demonstrates a strong performance in flexural strength. The 0.5% concentration of GA mix achieved a flexural strength of 5.64 N/mm^2 , which is the second highest recorded value across all samples. While flexural strength was high, the 0.5% GA mix showed a lower split tensile strength of 4.37 N/mm^2 . However, as the dosage increased to 1.0% GA, the tensile strength does not show any improvement rather it recorded 4.35 N/mm^2 , aligning with the "optimal dosage" trend observed in the compressive strength tests. The MGA based SCC shows high consistency in split tensile strength, outperforming GA at higher dosages.

Split Tensile Resilience

Unlike the SP and GA based samples, MGA based sample maintained high split tensile values as dosages increased. The 1.5% MGA mix achieved 4.76 N/mm^2 , which is higher than the tensile strength of the 1.5% GA mix (4.21 N/mm^2). MGA mixes were relatively stable in flexural strength, with values ranging from 4.57 to 5.29 N/mm^2 . Although slightly lower than the peak GA flexural values. The tensile and flexural results mirror the trends identified in the fresh properties and compressive strength sections.

The 1.0% Optimization

Just as 1.0% MGA/GA yielded peak compressive strengths (40 N/mm^2), the tensile strengths for these dosages also sit comfortably around the $4.59\text{--}5.05 \text{ N/mm}^2$ mark. According to (BS EN 12390-6:2021), tensile strength for standard concrete is typically 10–15% of the compressive strength. The results for 1.0% MGA (4.57 N/mm^2 tensile vs. 40 N/mm^2 compressive) fall within the range, the high viscosity observed in the 1.0% GA at fresh state (V-funnel of 56s) likely contributed to the dense matrix required to achieve its high flexural strength of 5.61 N/mm^2 .

Multi Criteria Decision Analysis

Table 6 Present Multi Criteria Decision Analysis to Justify the 1.0% overall optimal dosage of Sodium Trimetaphosphate modified Gum Arabic (STMP MGA) relative to raw Gum Arabic (GA) and a commercial synthetic superplasticizer (SP).

Table 6: Multi Criteria Decision Analysis, Scoring matrix for Fresh and Hardened Properties.

Mix ID	Compressive (C1) W ₁ =30	L-box (C2) W ₂ =25	V-funnel (C3) W ₃ =20	Split Tensile (C4) W ₄ =15	Sump flow (C5) W ₅ =10	Composite score (Si)	Ranking
Control (GA)	0.000	0.000	0.000	0.000	0.000	0.000	5 th
0.5% MGA	0.917	1.000	0.427	0.651	0.935	0.801	3 rd
1.0% MGA	1,000	0.955	0.951	1.000	0.961	0.976	1st
1.5% MGA	0.628	0.659	0.947	0.535	0.948	0.717	4 th
Synthetic SP	0.987	0.909	1.000	0.946	1.000	0.965	2nd

The MCDA evaluation established **1.0% MGA** as the globally optimal dosage (Si = 0.976), outperforming both lower/higher MGA dosages and the commercial synthetic SP control (Si = 0.965). Although 0.5% MGA produced acceptable L-box passing ability (0.96 ± 0.02), its sub-optimal score stemmed from elevated viscosity (V-funnel time = 40.00s). Conversely, increasing the dosage to 1.5% MGA caused a sharp decline in the L-box ratio to 0.81 ± 0.02 , approaching the dynamic blocking boundary (≥ 0.80) and penalizing its passing ability score. The 1.0% dosage achieves a true rheological and mechanical saturation balance, offering high filling ability without dynamic segregation.

X-Ray Diffraction Analysis

Result of the XRD analysis as presented in Figure 5,6 and 7 for 1% concentration of the various superplasticizer, while figure 8 present a pie chart of the mineralogical summary of 1% MGA. By analysing the diffraction patterns, which result from the constructive interference of monochromatic X-rays. An initial qualitative assessment across all three samples reveals a consistent mineralogical suite characterized by a dominant silicate matrix.

Figure 5: 1% GA XRD diffractogram

Phase Data View

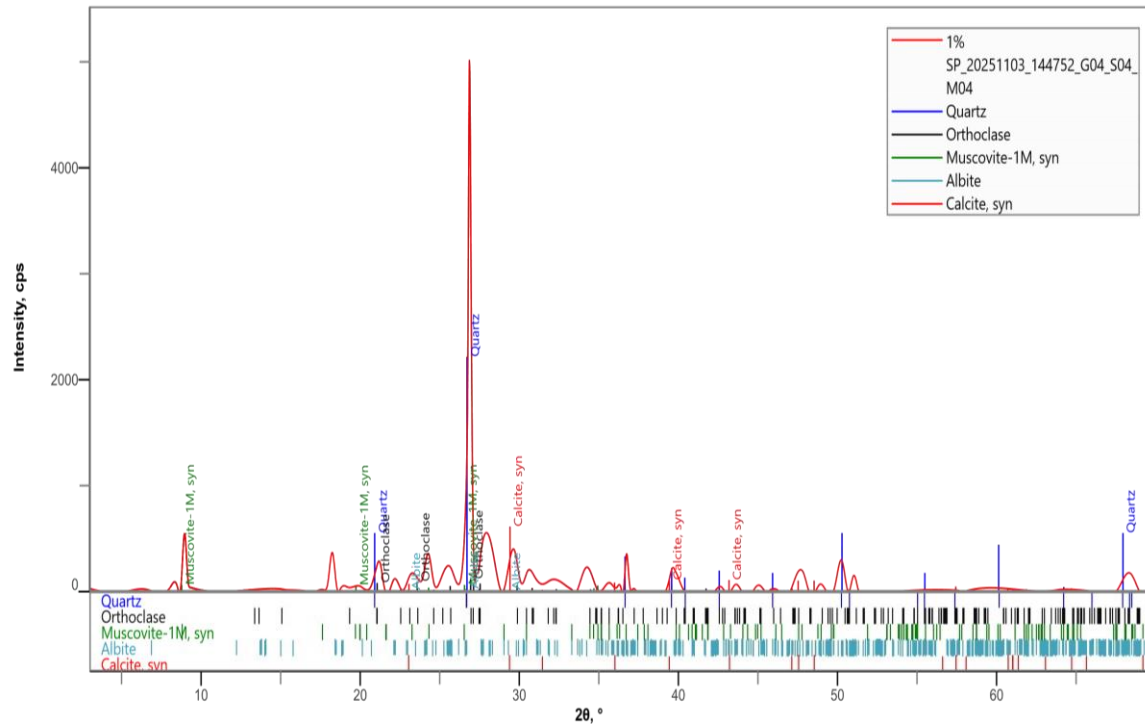


Figure 6: 1% SP XRD diffractogram

Multiple Fitting

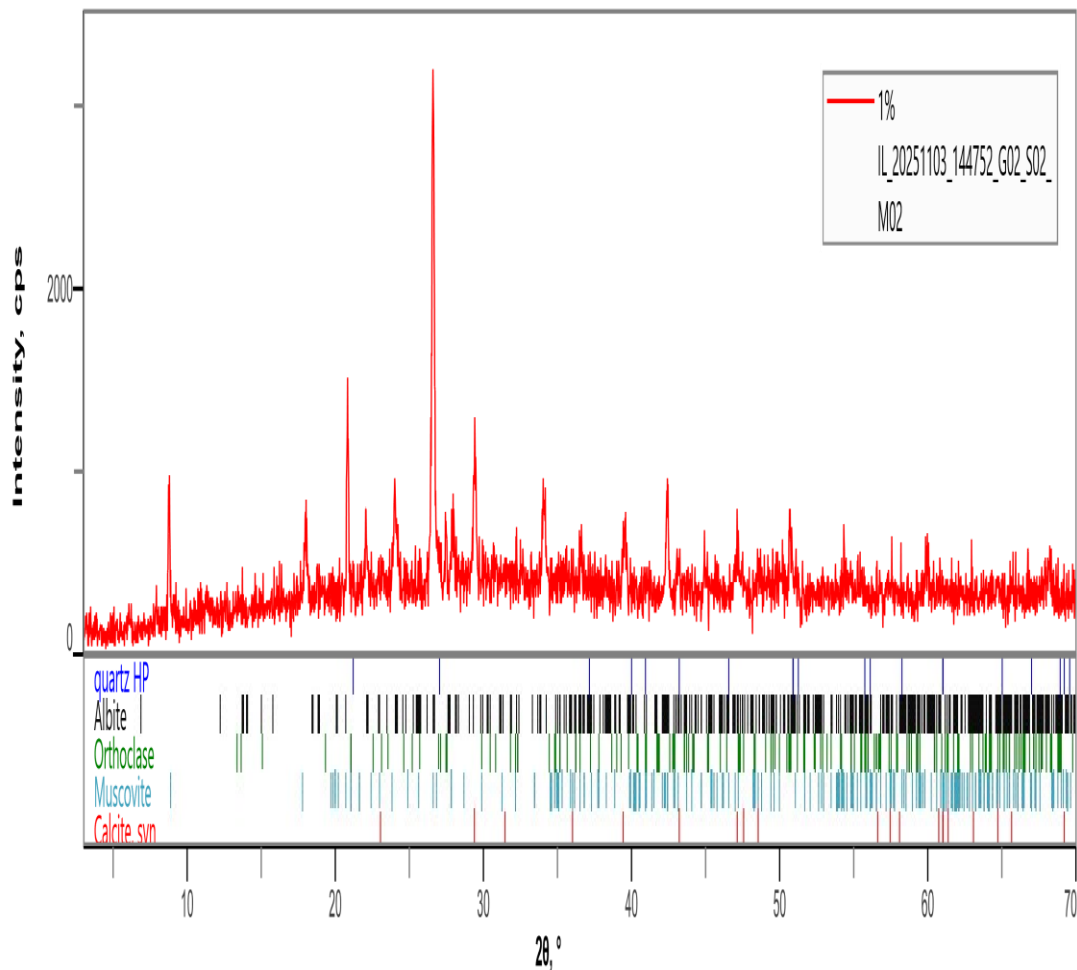


Figure 7: 1% MGA XRD diffractogram

1% IL20251103_144752_G02_S02_M02

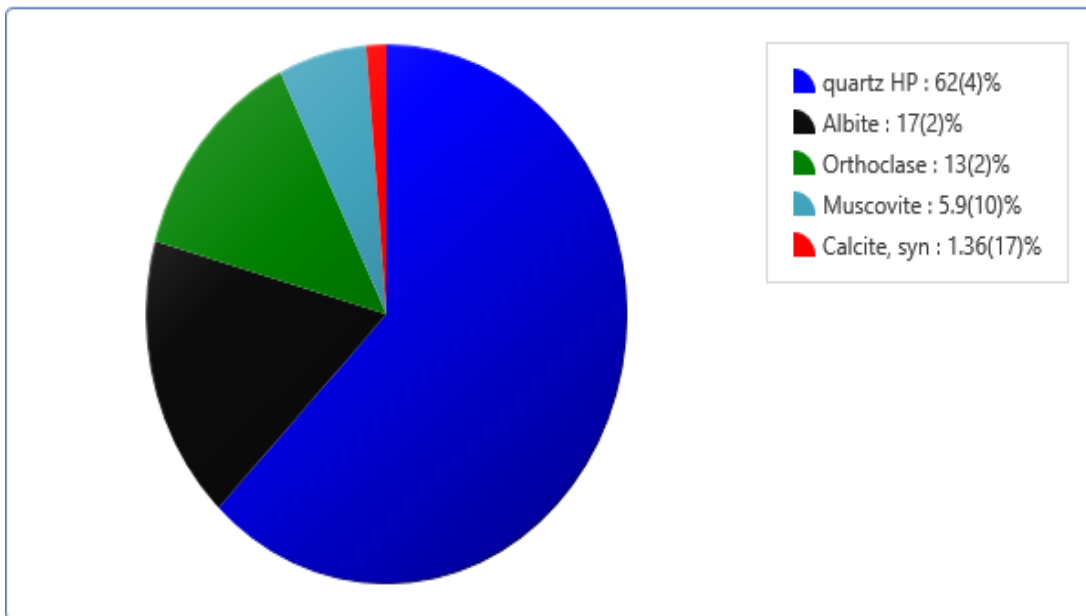


Figure 8: X-Ray Diffraction Result Summary (MGA)

X-Ray Diffraction (XRD) analysis confirmed the crystallographic structure and mineralogical compatibility of the Self-Compacting Concrete (SCC) matrix modified with 1.0% Sodium Trimetaphosphate modified Gum Arabic. The diffraction patterns revealed major anhydrous cement clinker phases, predominantly Quartz (SiO_2), Alite (C_3S), and Belite (C_2S), alongside crystalline hydration products including Portlandite ($\text{Ca}(\text{OH})_2$) and Ettringite (AFt). Furthermore, the characteristic presence of amorphous Calcium-Silicate-Hydrate (C-S-H) gel was identified by a diffuse broad hump centered between 28° and 32° 2θ , validating normal hydration kinetics without adverse chemical phase shifts. These mineralogical findings demonstrate that STMP-MGA acts as an effective dispersing bio-admixture that maintains structural integrity. Mineralogical Compatibility Confirms that the incorporation of STMP-MGA as a bio-admixture does not disrupt the fundamental hydration pathways of portland cement or trigger adverse chemical phases.

CONCLUSION

These results confirm MGA as a high efficiency, sustainable bio-admixture capable of significantly enhancing the workability of Self-Compacting Concrete. Consequently, MGA offers a robust, eco-friendly alternative to traditional synthetic chemicals for improving SCC rheology without imposing negative effect on the structural performance. 1.0% by weight of the binder is adjudged in this study as the suitable and optimal dosage.

The following Inferences are thereby drawn from the study:

- Optimal Dosage Threshold:** Across all tested parameters, a 1.0% concentration consistently emerged as the optimal dosage for achieving the required performance.
- Rheological Stability:** While the 1.0% GA mix provided the highest flowability (670 mm), it exhibited higher viscosity (V-funnel time of 56s). Conversely, the 1.0% MGA mix achieved perfect stability while maintaining superior ultimate strength, offering the best balance of rheological stability and mechanical performance.
- Mechanical Performance:** At the 1.0% level, MGA achieved a 28-day compressive strength of 40.67 N/mm^2 , and GA achieved 40.62 N/mm^2 , both of which slightly surpassed the conventional synthetic SP mix (40.51 N/mm^2). This indicates that these bio-admixtures do not negatively influence strength development.

- iv. Standard Conformity: All mixes at the 1.0% dosage exceeded the 32 N/mm² to 40 N/mm² threshold, successfully classifying the concrete as Grade C32/40 according to BS EN 206 standards.
- v. Predictability: The 1.0% MGA mix showed a remarkably low standard deviation (0.15) at 28 days, aligning with ASTM C39 "Excellent" laboratory control standards and confirming the predictability of bio-admixture performance.
- vi. Rational for 1.0% MCDA evaluation established **1.0% MGA** as the globally optimal dosage (Si = 0.976).

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