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Experimental Study on Self-Compacting Concrete Containing Granite Powder: Fresh, Mechanical, and Durability Properties

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Abstract: The increasing demand for construction-grade aggregates and the growing environmental problems associated with granite processing waste have motivated the present investigation. This study evaluates the viability of using granite powder as a partial replacement for natural fine aggregate in self-compacting concrete incorporating 25% fly ash. Granite powder was used at replacement levels ranging from 0% to 30%, and its effects on fresh properties, mechanical performance, and durability were investigated. Slump flow values were within the SF2 class range 660-750 mm, while V-funnel and L-box results showed satisfactory filling and passing ability. Optimum fresh properties were achieved at 20% replacement of granite powder, due to improved particle packing and filler effects. Mechanical properties improved gradually with increasing granite powder content up to 20% replacement. The maximum compressive strength of 46.9 MPa was recorded at 20% granite powder replacement, along with corresponding improvements in split tensile and flexural strengths. The improved performance is attributed to matrix densification, enhanced aggregate-paste bonding, and a refined pore structure resulting from the microfiller action of granite powder. Replacement levels above 20% led to reduced workability and strength due to excessive fines and increased water demand. The optimum mix containing 20% granite powder showed satisfactory durability, with water absorption of 3.0% and abrasion loss of 2.51%, indicating good resistance to water penetration and surface wear, respectively. Overall, incorporating 20% granite powder provided the best balance of fresh, mechanical, and durability properties. The findings show that granite powder is a viable alternative to river sand in SCC, reducing consumption of natural resources and promoting the utilization of industrial waste.

Keywords: self-compacting concrete, granite powder, fly ash, workability, mechanical strength, durability, sustainable construction.

I. INTRODUCTION

Concrete remains the most widely consumed manufactured material globally, with annual production exceeding 25 billion tonnes [1]. In India alone, the construction sector utilizes nearly 450 million m³ of concrete annually, resulting in significant depletion of natural aggregate resources. Aggregates constitute approximately 65-80% of the total concrete volume; therefore, sustainable replacement of natural aggregates can substantially reduce environmental degradation and conserve natural resources.

Simultaneously, India generates nearly 960 million tonnes of solid waste annually from industrial, mining, municipal, and agricultural activities, of which approximately 290 million tonnes originate from mining and industrial sectors [1]. Among these, the granite processing industry generates considerable waste during cutting, polishing, and finishing operations, with nearly 20-30% of quarried granite converted into unusable by-products in the form of coarse fragments and fine slurry. Improper disposal of granite waste raises serious environmental concerns, including air pollution from suspended particulate matter, contamination of soil and groundwater, and adverse health effects from prolonged exposure to granite fines.

In this context, the utilization of granite powder (GP) as a partial replacement for natural fine aggregate in concrete presents a promising sustainable alternative. Self-compacting concrete (SCC), originally conceptualized by Okamura in 1986 and later developed by Ozawa and Maekawa at the University of Tokyo in 1989, provides an effective matrix for incorporating such industrial by-products. SCC can flow, compact, and consolidate under its own weight without external vibration, thereby minimizing honeycombing and improving structural uniformity. Owing to its high paste volume and sensitivity to filler materials, SCC is particularly suitable for incorporating finely divided waste materials such as granite powder. The fresh-state performance requirements for SCC are governed by Indian Standards, including IS 10262, IS 456, IS 9103, and IS 1199 (Part 6):2018, which classify SCC based on filling ability, viscosity, and passing ability.

Extensive research has been conducted on the utilization of granite waste and related stone-processing residues in cementitious systems. Lozano-Lunar et al. [2] investigated the incorporation of granite sludge as a replacement for natural sand and siliceous filler in self-compacting mortars at replacement levels of 0%, 20%, and 40% by volume. Their findings indicated only marginal variations in compressive and flexural strengths at 7, 28, and 91 days, while durability characteristics remained largely unaffected, demonstrating the technical feasibility of high-volume granite sludge utilization in mortar systems.

Similarly, Jain et al. [3] evaluated SCC mixtures containing granite cutting waste as a fine aggregate replacement at levels ranging from 20% to 100%. Comprehensive assessment of fresh properties, including slump flow, T_{500}, V-funnel, L-box, and J-ring tests, together with hardened properties such as compressive, split tensile, and flexural strengths, water absorption, and abrasion resistance, revealed that mixes containing up to 40% replacement satisfied SCC performance requirements. The 40% replacement level exhibited optimum compressive strength and enhanced impermeability, supported by SEM and XRD analyses.

In conventional concrete applications, Vijayalakshmi et al. [10] replaced natural sand with granite powder waste at levels ranging from 0% to 25% and evaluated mechanical and durability characteristics. Their study concluded that 15% replacement represented the practical upper limit for unrestricted use, and recommended chemical treatment of granite powder to minimize sulphate-related deterioration. Arivumangai and Felixkala [9] investigated M30-grade concrete incorporating 25% and 50% granite powder, along with supplementary cementitious materials, and reported improved long-term strength development and enhanced chloride resistance. Li et al. [5] further demonstrated that granite dust significantly improved chloride penetration resistance in manufactured-sand concrete while maintaining a stable dynamic elastic modulus under freeze-thaw exposure up to 350 cycles at a replacement level of 20%. Studies linking other stone-processing wastes also back the beneficial role of mineral fines in cementitious composites. Khyaliya et al. [4] reported that marble waste replacement levels of 25% to 50% in lean mortars reduced water demand and significantly enhanced compressive strength. Singh et al. [12] and Syam Prakash et al. [13] observed that stone dust replacement levels of 30-40% maintained acceptable compressive strength while improving flexural performance.

Collectively, previous studies indicate two consistent trends: (i) the optimum granite powder replacement level generally lies between 15% and 25%, beyond which excessive fines adversely affect workability and mechanical performance; and (ii) limited studies have comprehensively integrated IS 10262:2019 mix design methodology, IS 1199 (Part 6):2018 SCC characterization, fly ash supplementation, and durability assessment within a unified M35-grade SCC framework.

Accordingly, the present study aims to address these research gaps by systematically replacing river sand with granite powder at 0%, 5%, 10%, 15%, 20%, 25%, and 30% by mass while maintaining a constant water-binder ratio, binder composition with 25% Fly ash cement substitution, and superplasticizer dosage. The investigation focuses on: (i) evaluating fresh-state SCC behavior across varying granite powder contents; (ii) determining 7-day and 28-day mechanical properties; (iii) assessing durability characteristics, including water absorption and abrasion resistance; and (iv) identifying the optimum granite powder replacement level that simultaneously satisfies performance and sustainability requirements.

II. MATERIALS AND EXPERIMENTAL PROGRAM

A. Raw Materials

1) Cement

Ordinary Portland Cement (OPC) 43-grade conforming to IS 8112:2013 [19] was employed, sourced from a single production lot to ensure batch-to-batch uniformity. The 28-day compressive strength of 43.25 MPa exceeded the minimum IS requirement of 33 MPa. Physical properties are summarised in Table 1.

Table 1. Physical properties of OPC 43-grade cement

Property	Measured Value	IS Requirement
Specific gravity	3.10	-
Normal consistency	31%	-
Initial setting time	90 min	≥ 30 min
Final setting time	210 min	≤ 600 min
28-day compressive strength	43.25 MPa	≥ 33 MPa

2) Fine Aggregate

Zone II natural river sand conforming to IS 383:2016 [18] served as the reference fine aggregate. Specific gravity was 2.65, fineness modulus 2.75, and water absorption 1.01%.

3) Coarse Aggregate

Crushed granite conforming to IS 383:2016 with a nominal maximum size of 20 mm was adopted. Aggregate crushing value 21.5%, impact value 18.6%, and Los Angeles abrasion value 28.0% all satisfied the IS 383 thresholds of 30%, confirming mechanical competence.

4) Fly Ash

Class F fly ash meeting IS 3812:2013 was incorporated at a fixed mass replacement of 25% by cementitious content to improve long-term durability and enhance workability through its spherical particle morphology and secondary pozzolanic reactivity.

5) Granite Powder

Granite powder (GP), obtained as a by-product from a local granite stone-processing industry, was used as a sustainable fine aggregate replacement material. The GP possessed a specific gravity of 2.68, bulk density of 2552 kg/m³, and water absorption of 1.40%.

Table 2. Physical Properties of Granite Powder

Property	Value
Appearance	White powder
Specific Gravity	2.68
Bulk Density (kg/m^3)	2552
Water Absorption (%)	1.40

6) Superplasticiser

A polycarboxylate-ether -PCE high-range water-reducing admixture (MasterGlenium Sky 8233) having a specific gravity of 1.10, chloride content nil, and recommended dosage 1.0-4.0% by binder mass.

7) Water

Potable municipal water satisfying IS 456:2000 [21] quality provisions was used throughout.

B. Mix Design Methodology

Mix proportioning for M35-grade SCC was in accordance with IS 10262:2019 [17]. The target mean strength was: $f'ck = fck + 1.65\sigma = 35 + 1.65 \times 5.0 = 43.25$ *MPa.*

A water-binder ratio of 0.38 was selected from the IS 10262:2019 strength-binder ratio chart Curve 2, OPC 43, also satisfying the IS 456:2000 durability constraint of w/b ≤ 0.45 for moderate exposure. Applying a 20% reduction in superplasticizer use, the water content was fixed at 150 L/m^3. The total binder content was 395 kg/m^3, distributed as 296 kg/m^3 of cement and 99 kg/m3 of fly ash. After trials, the superplasticizer dosage was fixed at 1.2% of the binder mass (4.74 kg/m^3). Coarse aggregate was fixed at 1414 kg/m^3, and the remaining aggregate volume was distributed to fine aggregate 481 kg/m^3 for the control. GP substituted river sand at 0, 5, 10, 15, 20, 25, and 30% by mass across seven trial mixes, T1-T7, as detailed in Table 3.

Table 3. Trial mix proportions for M35-grade SCC (kg/m^3)

Mix ID	GP (%)	Sand (kg)	GP (kg)	Cement (kg)	Fly Ash (kg)	Water (kg)	CA (kg)	SP (kg)
T1	0	481	0	296	99	150	1414	4.74
T2	5	457	24	296	99	150	1414	4.74
T3	10	433	48	296	99	150	1414	4.74
T4	15	409	72	296	99	150	1414	4.74
T5	20	385	96	296	99	150	1414	4.74
T6	25	361	120	296	99	150	1414	4.74
T7	30	337	144	296	99	150	1414	4.74

C. *Specimen Preparation and Curing*

Batches were produced in a 50-liter tilting drum mixer at 18 rpm, following EFNARC and IS 10262:2019 protocols: 2 min of dry mixing, 1 min of gradual addition of water-superplasticizer solution, followed by 2 min of wet mixing, for a total of 5 min at 27 ± 2 °C. No external compaction was applied. Molds were oiled, filled in a single pour from a height ≤ 500 mm, and surface-finished with a trowel. After 24-h sealed rest, specimens were demoulded and water-cured at 27 ± 2 °C until the test age. Specimen geometries are given in Table 4.

Table 4. Test specimen specifications.

Test	Type	Size (mm)	Quantity per Mix
Compressive strength	Cube	150 × 150 × 150	6 (3 at 7 d; 3 at 28 d)
Split tensile strength	Cylinder	Ø150 × 300	3 at 28 d
Flexural strength	Prism	100 × 100 × 500	3 at 28 d
Water absorption	Cube	150 × 150 × 150	3 at 28 d (T1, T5)
Abrasion resistance	Slab	Per IS 1237:2012	3 at 28 d (T1, T5)

D. *Test Methods*

1) *Fresh Properties (IS 1199 Part 6:2018)*

Three tests were conducted within 15 min of mixing at 27 ± 2 °C and 65 ± 5% RH. The slump flow test, Abrams cone, 900 × 900 mm steel plate, measured the filling ability; the mean of two perpendicular diameters defined the SF class: SF1: 550-650 mm; SF2: 660-750 mm; SF3: 760-850 mm. T500 spread time served as a secondary viscosity indicator; acceptable range: 2-5 s. The V-funnel test (65 × 75 mm outlet) quantified viscosity; discharge time VF1: 6-12 s. The L-box test (three Ø12 mm bars at 40 mm spacing) evaluated passing ability via the H_2/H_1 ratio (≥ 0.80 = satisfactory; ≥ 0.85 = good).

2) *Mechanical Properties*

Compressive, split tensile, and flexural strength were determined at 7 and 28 days as per IS 516: Part 1: Sec 1: 2021 [20]. A minimum of 3 cubes were tested for each parameter, and the mean result is reported.

3) *Durability Properties*

Water absorption was calculated according to IS 3812:2013 as [(W2 - W1)/W1] × 100, where W1 and W2 are the oven-dry and 24-h water-immersed masses, respectively. Abrasion resistance in accordance with IS 1237:2012 was measured and expressed as percentage mass loss = $[(W_1 - W_2)/W_1] \times 100$. Both tests were performed on T1 and T5 at 28 days.

III. RESULTS AND DISCUSSION

A. *Fresh-State Behavior*

1) *Slump Flow and T500*

Results are compiled in Table 5. All mixes with GP ≤ 25% satisfied the SF1 or SF2 classification of IS 1199 (Part 6):2018, confirming adequate filling ability when an appropriate superplasticizer dosage is maintained. Flow diameter increased from 655 mm (T1, 0% GP) to a peak of 715 mm (T3, 10% GP), attributable to the microfiller effect of fine granite particles, which improved particle packing and lubricated the mix. A gradual decline was subsequently recorded, with T7 30% GP falling to 615 mm, below the SF1 lower bound. The T500 time followed an inverse trend, rising from 3.0 s at T3 to 5.2 s at T7, confirming that high GP content elevates viscosity through increased fine-particle surface area and higher water demand.

Table 5. Slump flow and T500 results.

Mix ID	GP (%)	SP (% binder)	Slump Flow (mm)	T500 (s)	SF Class
T1	0	1.0	655	3.8	SF1
T2	5	1.0	685	3.4	SF2
T3	10	1.1	715	3.0	SF2
T4	15	1.1	705	3.2	SF2
T5	20	1.2	665	3.9	SF2
T6	25	1.2	645	4.5	SF1
T7	30	1.3	615	5.2	SF1

2) V-Funnel Flow Time

V-funnel results in Table 6 indicated VF1-class performance for T1 through T6, with times ranging from 7.6 s for T4 and T5 to 11.5 s for T6. The reduction from T1 8.5 s to T4-T5 7.6 s reflects beneficial particle packing at intermediate GP levels, reducing internal frictional resistance. T7 30% GP recorded 13.0s, falling outside the VF1 range and exhibiting a sticky, high-viscosity behavior attributed to excess fines that absorb free water and impede flow through the narrow funnel outlet.

Table 6. V-funnel test results.

Mix ID	GP (%)	V-Funnel Time (s)	VF Class	Observation
T1	0	8.5	VF1	Uniform flow
T2	5	8.0	VF1	Improved flow
T3	10	7.8	VF1	Very smooth
T4	15	7.6	VF1	Optimum
T5	20	7.6	VF1	Optimum
T6	25	11.5	VF1 marginal	Sticky mix
T7	30	13.0	Outside VF1	Poor flow

3) L-Box Passing Ability

L-box H_2/H_1 ratios Table 7 showed excellent passing ability for GP replacement levels of 10-15% H_2/H_1 = 0.95, with the control recording 0.91. A decline was observed beyond 20% GP: T5 at 0.89, while T7 had a ratio of only 0.75, below the IS 1199 threshold of 0.80. This deterioration is mechanistically consistent with higher viscosity impeding concrete flow through the reinforcement spacing in the L-box. The results identify T3-T5 as the workability-optimal range, with T5 at the upper boundary for satisfactory L-box performance.

Table 7. L-box test results.

Mix ID	GP (%)	H_1 (mm)	H_2 (mm)	H_2/H_1	Passing Ability
T1	0	195	186	0.91	Good
T2	5	196	189	0.93	Very good
T3	10	197	192	0.95	Excellent
T4	15	196	191	0.95	Excellent
T5	20	195	185	0.89	Acceptable
T6	25	194	178	0.83	Marginal
T7	30	193	170	0.75	Unsatisfactory

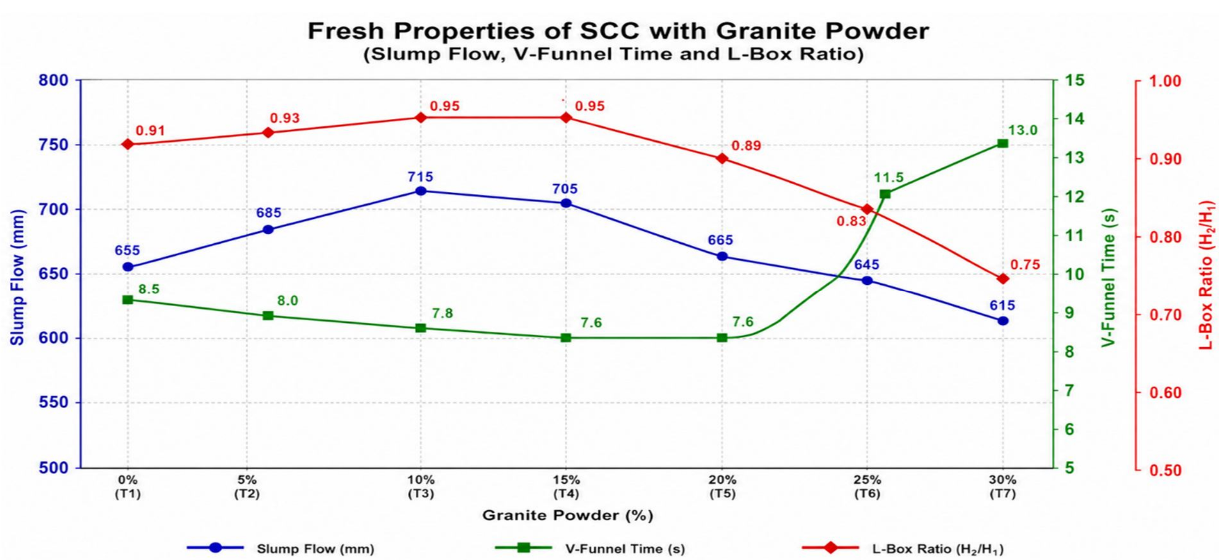

Figure 1: Variation in fresh properties of self-compacting concrete containing different granite powder replacement levels.

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B. Mechanical Properties

1) Compressive Strength

Results at 7 and 28 days are reported in Table 8 and Figure 2. The 28-day strength increased from 38.8 MPa T1 to a peak of 46.9 MPa at T5 (20% GP), a 20.9% improvement over the control. This progressive densification is attributed to the microfiller effect of fine granite particles occupying interstitial voids within the cement paste matrix, refining the pore structure and reducing effective porosity [3,10]. The aluminosilicate phases in granite powder also participate in secondary pozzolanic reactions, contributing additional C-S-H gel formation over time [9].

Beyond 20% GP, strength results were observed for T6 at 43.2 MPa, and for T7 only at 41.0 MPa. This is due to two: (i) excess fines elevate water demand, increasing effective w/b and porosity; and (ii) surplus fine particles dilute the cementitious fraction and weaken the interfacial transition zone (ITZ). The 7-day trend paralleled 28-day behavior, confirming that the filler effect is active from early hydration stages.

Table 8. Compressive strength results.

Mix ID	GP (%)	7-Day (MPa)	28-Day (MPa)	Change vs. Control (28 d)
T1	0	26.5	38.8	-
T2	5	27.8	40.5	+4.4%
T3	10	29.4	42.7	+10.1%
T4	15	31.0	44.6	+14.9%
T5	20	32.8	46.9	+20.9%
T6	25	30.5	43.2	+11.3%
T7	30	28.6	41.0	+5.7%

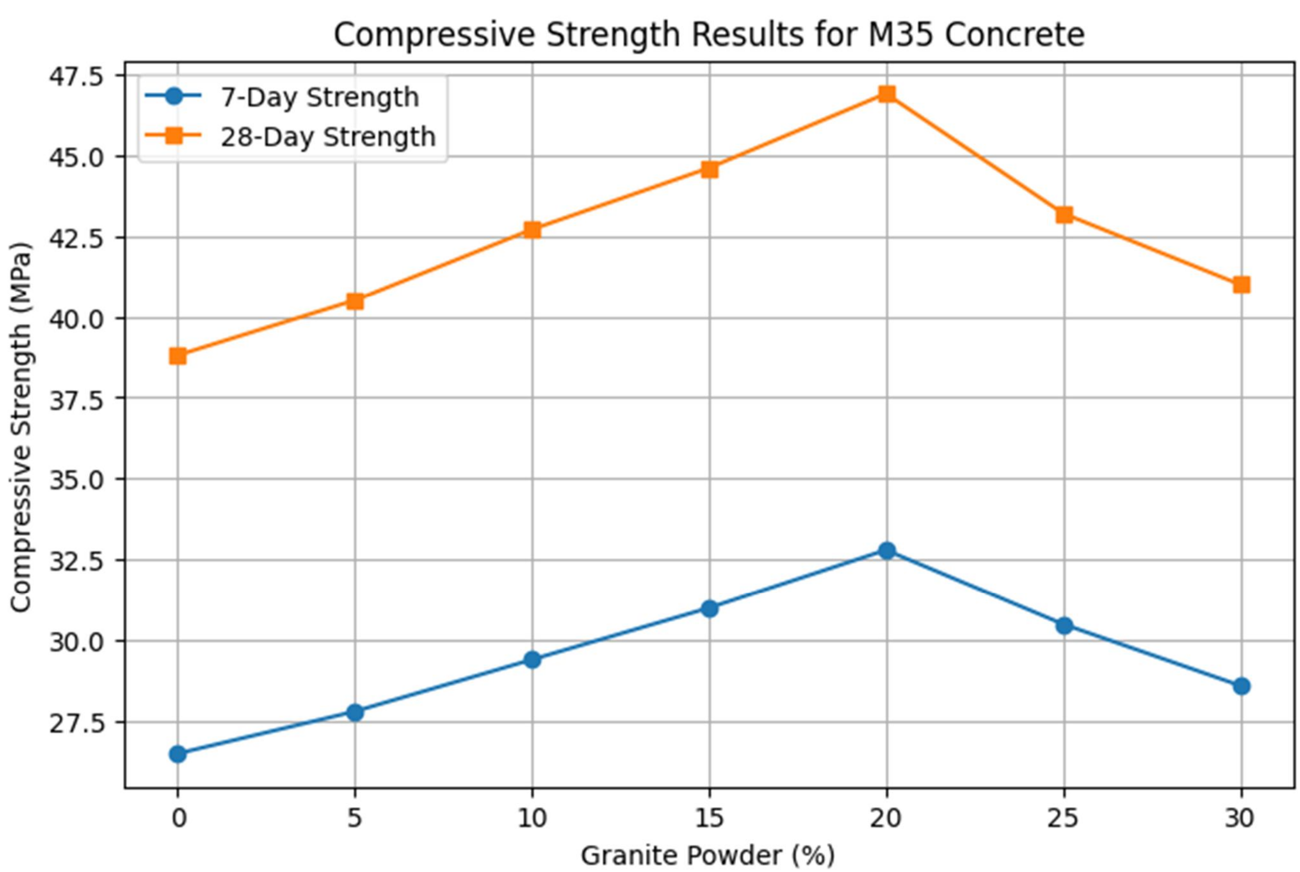

Figure 2: Compressive Strength results with different GP percentages (at 28 days)

2) Split Tensile Strength

Split tensile strengths at 28 days are reported in Table 9, and Figure 3 shows that they increased from 3.15 MPa (T1) to 4.05 MPa (T5), a 28.6% improvement. Enhanced particle packing at the ITZ reduces microcrack density and improves stress transfer efficiency between the aggregate and the cement paste [3]. The 25% (3.72 MPa) and 30% (3.48 MPa) GP declines are consistent with increased porosity and ITZ deterioration documented in the compressive strength data.

Table 9. Split tensile strength results (28 days).

Mix ID	GP (%)	Split Tensile Strength (MPa)	Change vs. Control
T1	0	3.15	-
T2	5	3.32	+5.4%
T3	10	3.55	+12.7%
T4	15	3.78	+20.0%
T5	20	4.05	+28.6%
T6	25	3.72	+18.1%
T7	30	3.48	+10.5%

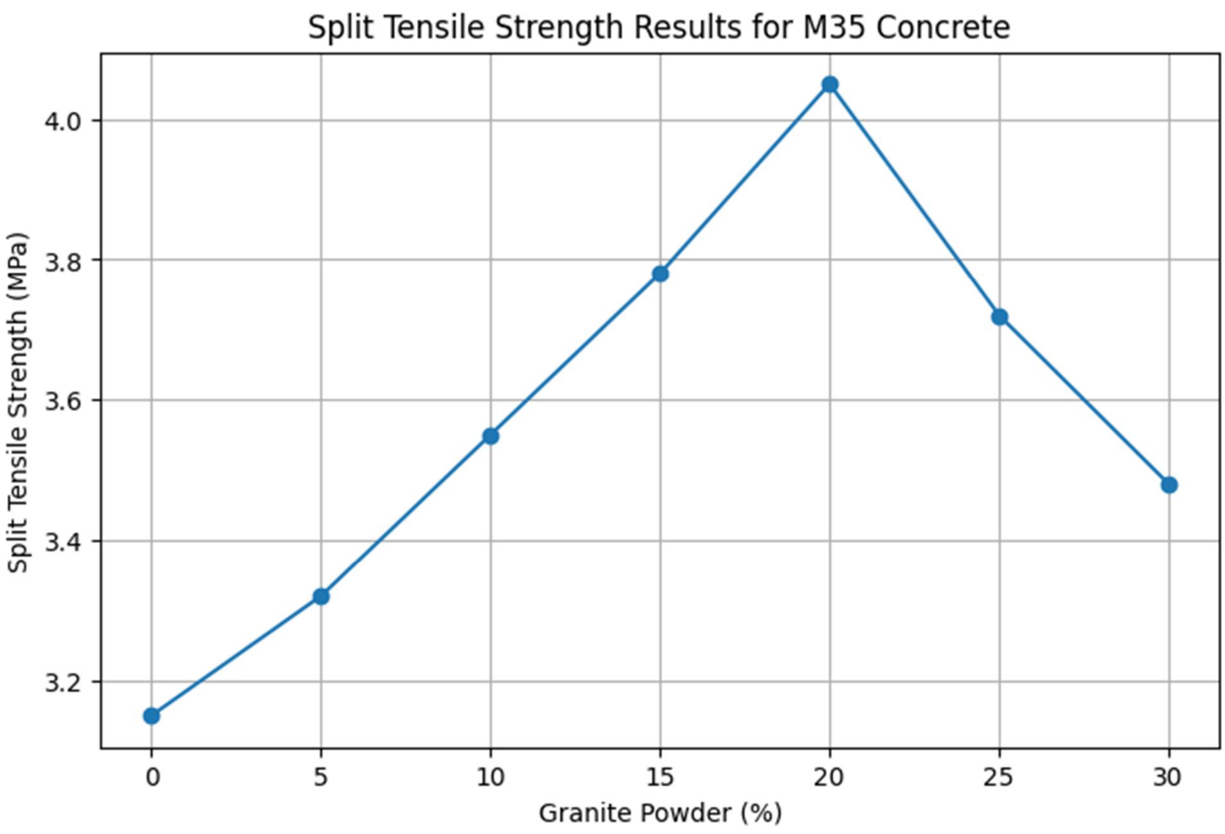

Figure 3: Split Tensile Strength results with different GP percentages (at 28 days)

3) Flexural Strength

Flexural strength, as shown in Table 10 and in Figure 4, increases from 4.6 MPa at T1 to a high of 5.9 MPa at T5 20% GP, a 28.3% gain. The micro-filler effect improves aggregate-paste interfacial bonding and matrix continuity, increasing resistance to crack propagation under four-point bending [15,16]. Post-peak reductions to 5.4 MPa in T6 and 5.1 MPa in T7 are indicative of brittleness associated with excess fines and a weakened ITZ. All tested mixes exceeded the code-specified minimum flexural strength for M35-grade concrete, confirming structural adequacy across the entire replacement range.

Table 10. Flexural strength results (28 days).

Mix ID	GP (%)	Flexural Strength (MPa)	Variation vs. Control
T1	0	4.6	-
T2	5	4.9	+6.5%
T3	10	5.2	+13.0%
T4	15	5.5	+19.6%
T5	20	5.9	+28.3%
T6	25	5.4	+17.4%
T7	30	5.1	+10.9%

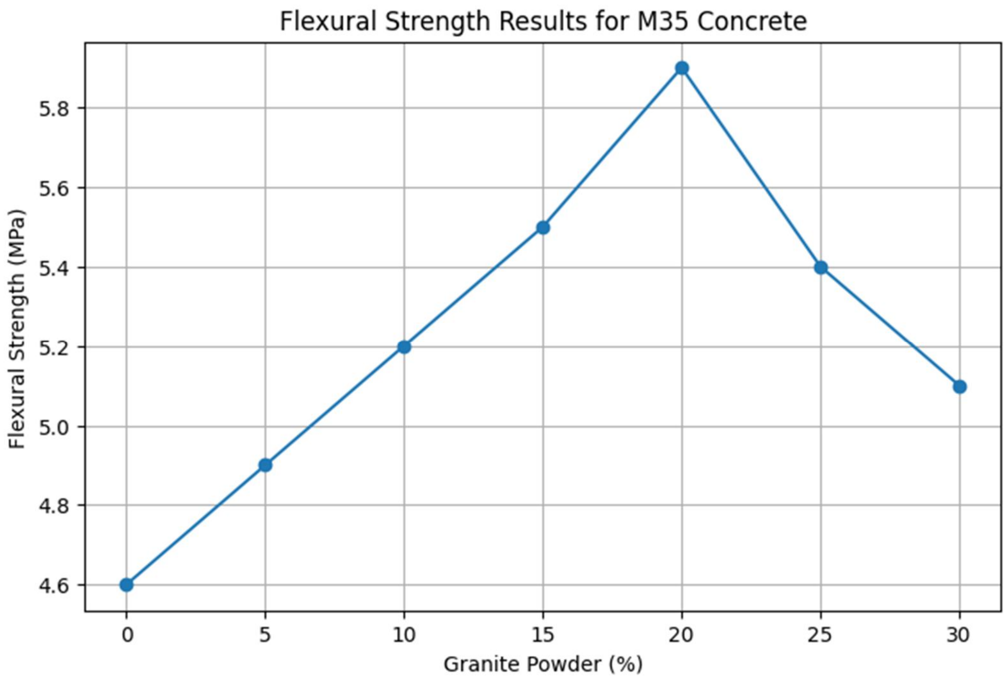

Figure 4: Flexural Strength results with different GP percentages (at 28 days)

C. Durability Properties

Durability properties were evaluated for the control (T1) and the optimum mix (T5) with 20% GP at 28 days, and the results are presented in Table 11.

Table 11. Water absorption and abrasion resistance (28 days).

Mix ID	Water Absorption (%)	Initial Weight, W1 (g)	Final Weight, W2 (g)	Weight Loss (g)	Abrasion Loss (%)	Durability Grade
T1 (Control)	2.8	320.0	309.76	10.24	3.2	Excellent
T5 (20% GP)	3.0	322.0	313.92	8.08	2.51	Good

Water absorption in T5 increased marginally to 3.0% from 2.8% in T1, representing a 7.1% increase. This slight rise may be attributed to the finer particle size and higher specific surface area of granite powder, which can increase capillary water ingress despite overall matrix densification. Nevertheless, both values remain well below the 5% limit generally considered acceptable for durable structural concrete, indicating satisfactory resistance to water ingress. In contrast, T5 exhibited significantly improved abrasion resistance, with abrasion loss decreasing from 3.2% in T1 to 2.51%, corresponding to a 21.6% reduction.

This improvement can be attributed to the micro-filler effect and the inherent hardness of granite powder, which enhance particle packing, strengthen the paste-aggregate interface, and produce a denser, more wear-resistant surface layer. These results indicate that the incorporation of 20% granite powder improves the durability performance of SCC, particularly in applications subjected to surface wear and abrasion.

IV. CONCLUSIONS

This study investigated the effect of replacing natural river sand with granite powder at 0-30% in M35-grade self-compacting concrete designed per IS 10262:2019 and evaluated against IS 1199 (Part 6):2018. The following conclusions are drawn:

1) All mixes with GP ≤ 20% satisfied the SF2 slump flow, i.e., 660-750 mm, and VF1 V-funnel class 6-12 s, confirming compatibility with SCC workability requirements when appropriate superplasticizer dosage is maintained.
2) L-box H_2/H_1 ratios peaked at 0.95 for 10-15% GP and remained acceptable at 0.89 for 20% GP, before dropping below the IS 1199 threshold of 0.80 at 30% GP, marking 20% as the practical upper bound for passing ability.
3) A 20% GP replacement delivered maximum 28-day compressive strength 46.9 MPa, split tensile strength 4.05 MPa, and flexural strength 5.9 MPa, representing improvements of 20.9%, 28.6%, and 28.3% over the control mix. These improvements are linked to the microfiller effect of fine granite particles, which densify the cementitious matrix and improve aggregate-paste interfacial bonding.
4) Durability assessment showed that the optimum mix exhibited a marginal increase in water absorption 3.0% compared to the control mix, 2.8%. In comparison, abrasion loss decreased from 3.2% to 2.51%, representing a 21.6% improvement in abrasion resistance.
5) The use of granite powder promotes viable concrete production by reducing dependence on river sand and aiding the beneficial utilization of industrial waste materials.

A. *Future Scope*

Future research should incorporate microstructural characterization (e.g., SEM, XRD, EDS), long-term durability studies (e.g., chloride penetration, sulphate resistance, carbonation, freeze-thaw cycling), and field-scale validation to apply these laboratory findings in practical construction applications.

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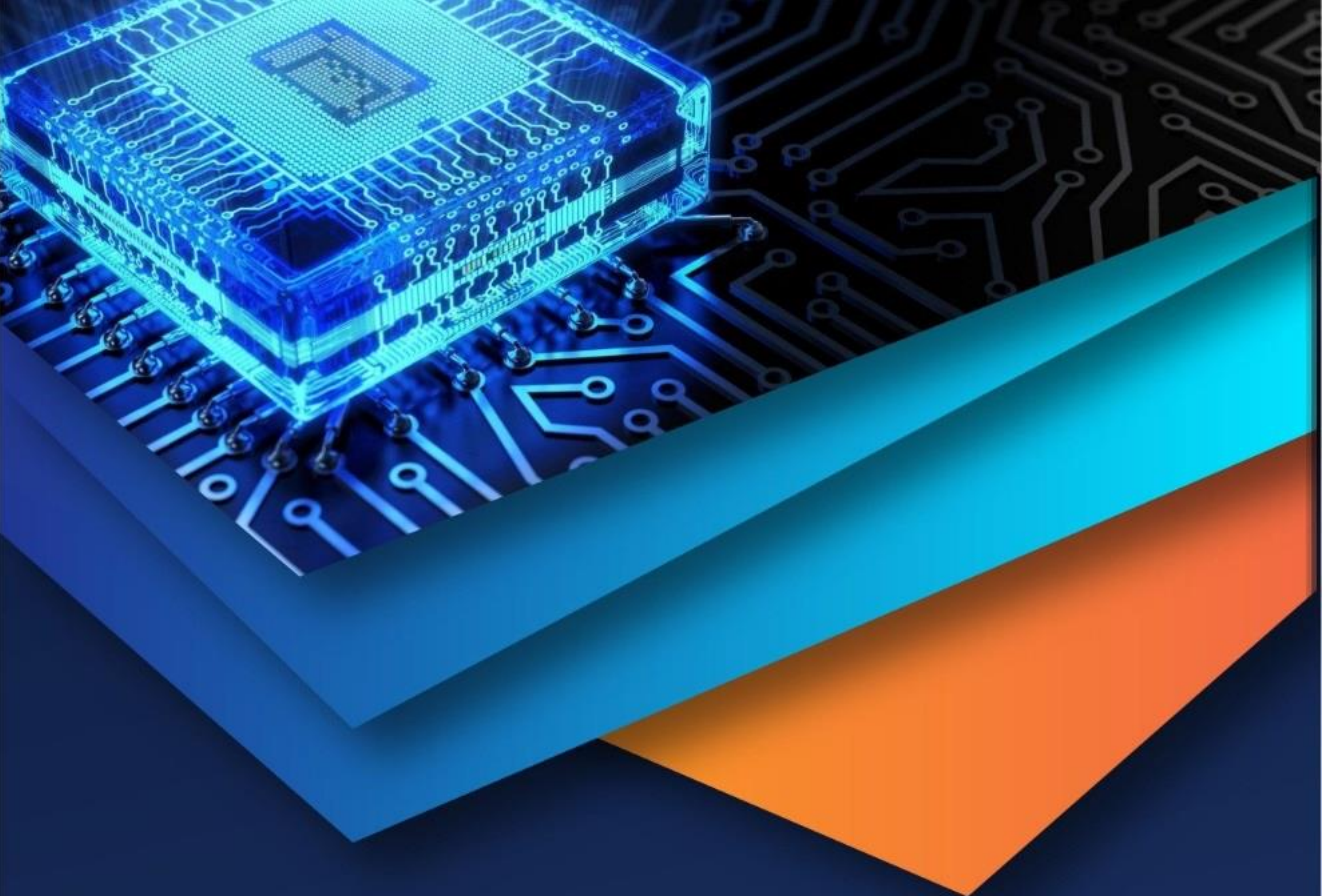

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