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Sustainable Self-Compacting Concrete with Partial Replacement of Cement with Ceramic Tile Waste Powder and Fine Aggregate with Slag Sand

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Abstract: The rapid growth of the construction industry has intensified the consumption of natural resources and raised the carbon footprint of cement manufacturing. To address these environmental concerns, the development of sustainable high-performance concretes has become essential. This study focuses on producing M60 grade Self-Compacting Concrete (SCC) using ceramic tile waste powder (CTWP) as a partial cement replacement and slag sand as an alternative fine aggregate. Ground granulated blast furnace slag (GGBS) was used as the sole supplementary cementitious material to enhance the strength and durability of the mixes. SCC mixtures were prepared by replacing cement with CTWP at 5%, 10%, 15%, and 20%, and after determining the optimum CTWP percentage, fine aggregate was partially replaced with slag sand at 10%, 20%, 30%, and 40%. Fresh properties like Slump flow, L-Box, V-funnel are also conducted .Hardened properties including compressive, split tensile, and flexural strengths were assessed to determine the effect of CTWP and slag sand replacements on mechanical performance. The results indicated that the incorporation of CTWP and slag sand can effectively produce a sustainable SCC mix without compromising strength, while promoting waste utilization and reducing the dependence on natural river sand and cement. This study demonstrates the potential of ceramic waste and slag sand as eco-friendly materials for high-strength SCC applications.
Keywords: Self-Compacting Concrete (SCC), Ceramic Tile Waste Powder (CTWP), Slag Sand, GGBS, M60 Grade Concrete, Sustainable Concrete.

I. INTRODUCTION

In the modern construction ecosystem, cement production is recognized as a major contributor to environmental pollution, particularly through carbon dioxide (CO_2) emissions. The cement industry is one of the most carbon-intensive industries, contributing around 7% of the world's CO2 emissions.. These emissions, generated during the manufacturing of Ordinary Portland Cement (OPC), adversely affect the environment, human health, and natural ecosystems. Furthermore, cement production involves energy-intensive processes, large-scale material handling, and significant resource consumption, all of which contribute to environmental degradation. To reduce these impacts, sustainable alternatives to conventional concrete have become increasingly important. One promising approach is the utilization of industrial and construction-based waste materials in concrete production. In this direction, ceramic tile waste powder (CTWP), which is rich in silica and alumina, can serve as a partial replacement for cement due to its filler and pozzolanic characteristics. Similarly, slag sand, a by-product of the steel industry, offers a viable substitute for natural river sand, helping to minimize excessive sand mining and reduce ecological disruption. Adopting such waste-derived materials not only conserves natural resources but also lowers the embodied carbon associated with high-strength concrete production. In the present study, M60 grade Self-Compacting Concrete (SCC) was developed by partially replacing cement with CTWP at varying percentages and fine aggregate with slag sand at 10%, 20%, 30%, and 40%. GGBS was incorporated as the supplementary cementitious material to enhance strength and durability. These modifications aim to produce an eco-friendly SCC with improved performance while minimizing the environmental burden created by conventional concrete constituents.

II. REVIEW OF LITERATURE

Assaggaf et al.[1] Durability and Mechanical Behaviour of Mortar with Ceramic Polishing Sludge Investigated Using 10–50% CPS improved durability and pore refinement while maintaining acceptable strength. Even at high replacement, the mix satisfied ASTM limits, proving CPS to be an effective sustainable binder.

Joshi et al. [2] studied Mechanical and Durability Performance of Ceramic Tile Waste Aggregates Low-absorption CTW aggregates enhanced compressive, tensile and flexural strength up to 60% replacement. Improved microstructure and reduced permeability confirm CTW as a viable coarse aggregate alternative.

Murali et al. [3] investigated Ceramic Waste Powder as a Supplementary Cementitious Material. Moderate CWP levels (5–10%) increased strength and improved densification due to pozzolanic action. Higher dosages reduced strength, indicating that controlled CWP addition enhances sustainable concrete.

Lietal.[4] Performance of Mortar Using Recycled Fine Ceramic Aggregates A 20% ceramic aggregate replacement significantly increased strength and reduced permeability. Microstructure results confirm denser ITZ formation, making CA a sustainable sand replacement.

Li et al.[5] investigated Use of Household Ceramic Waste as Cement and Sand Replacement Strength and durability improved at 20–40% replacement due to enhanced bonding and pore refinement. Excessive ceramic content reduced compactness, showing the need for controlled replacement ratios.

Al-Fakih et al. [6] studied Ceramic Polishing Sludge as a Cement Replacement in Mortar.CPS at 10–20% improved compressive and tensile properties through densified microstructure. Higher levels caused porosity and strength loss, proving the benefit of moderate dosage.

Wei et al. [7] investigated Steel-Slag–Ore-Slag Binder (SSR) in Recycled Aggregate Concrete Optimum slag and fly ash proportions produced strength comparable to OPC mixes. SSR concretes showed better sulphate resistance, highlighting their durability and sustainability.

Li et al. [8] studies on the Creep Behaviour of Steel-Tube Columns with Steel-Slag Aggregate Concrete Replacing natural aggregates with steel slag reduced creep and increased compressive strength. Its stiffness and dimensional stability make steel slag a reliable aggregate for structural systems.

Azhagarsamy et al.[9] investigated Behaviour of Concrete with Steel Slag Fine Aggregate SSA improved long-term strength and durability, especially at ~70% replacement. Enhanced microstructure and resistance to chloride attack confirm SSA as a strong sustainable alternative.

Al-Shugaa et al.[10] Studies on the PoZZolanic Activity of Ceramic Polishing Sludge in Blended Cement CPS displayed good pozzolanic reactivity and maintained strength up to 40% replacement. Improved microstructure and reduced porosity indicate CPS’s suitability as a green cementitious material.

Fu & Lee [11] investigated on theUse of Ceramic Tile Waste in Construction Materials Ceramic waste improves strength by 10–30% at optimal levels due to better bonding. Overuse leads to workability issues, highlighting the need for proper proportioning.

Zheng & Deng [12] studied on Geopolymer Concrete with Recycled Aggregates and Steel Slag Strength reduced with recycled aggregates but fracture resistance improved with 25% steel slag. High slag levels weaken the matrix, showing that moderate addition is most effective.

Tanash et al. investigated the [13] Use of Ceramic Tile Waste in Cement and Aggregate Replacement CTW improves strength (5–25%) up to moderate levels due to surface roughness and partial pozzolanic action. Excess content decreases compaction, marking optimum ranges as essential for performance.

Chang et al. [14] studies on Strength Prediction of Concrete Containing Ceramic Waste Powder Increasing CWP lowered compressive strength, though moderate levels still maintained structural adequacy.ML models confirmed reliable strength prediction, supporting CWP’s use for eco-friendly concretes.

Meena et al. [15] studied onSelf-Compacting Concrete with Waste Ceramic Tile Fine Aggregate Up to 60% WCT replacement increased strength and improved acid resistance. Microstructural studies confirmed denser C–S–H and reduced voids, validating its durability benefits.

Mohit et al. [16] investigated on the Ternary Blends with Ceramic Waste Powder and Limestone Powder 10% CWP + 15% LSP gave superior strength via synergistic pozzolanic and filler effects. ASR expansion reduced significantly, proving the blend effective for durable construction.

Jain et al. [17] studied on Ceramic ETP Sludge as SCM in Concrete Only 10% replacement improved strength through filler packing. Higher sludge content weakened the matrix, making it unsuitable beyond low dosages.

Meena et al.[18] investigated on SCC Using Waste Ceramic Tile Aggregates Strength and durability peaked at 60% WCT due to improved interlocking and pore refinement. Excessive replacement increased voids and reduced workability. Microstructural results confirm higher porosity at high CPW levels, explaining reduced strength.

III. MATERIALS AND ITS PROPERTIES

A. Materials

1) Cement

In this research, JSW Ordinary Portland Cement (OPC) of 53 grade served as the main binding agent. OPC is produced by thoroughly grinding clinker that is made from limestone, clay, and other corrective materials, with gypsum added to control the setting time. The manufacturing process includes calcination and clinkering of the raw materials, resulting in compounds like tricalcium silicate (C_3S) and dicalcium silicate (C_2S), which play a role in both early strength and long-term durability. The cement utilized in this study was obtained from JSW Cement located in Andhra Pradesh. The specific gravity of OPC 53 grade cement is 3.15, which shows good density and appropriateness for high-strength concrete such as M60 grade SCC. Cement fineness is 3%, cement's standard consistency is 33%, the initial setting time for cement is 42 minutes, and the final setting time is 256 minutes. In the current research, 53 grade OPC adhering to IS 12269-1987 was utilized.

2) GGBS

Ground Granulated Blast Furnace Slag (GGBS) is obtained as a secondary product during the iron-making process in blast furnaces. These furnaces operate at nearly 1500°C, where iron ore, fluxes, and other raw materials are melted to produce molten iron. During this process, the non-metallic components rise to the surface as slag. For GGBS production, the molten slag is rapidly cooled or quenched with large quantities of water, transforming it into glassy granules similar in size to coarse sand. After drying, these granules are finely ground to form a highly reactive powder commonly referred to as GGBS or slag cement. The material exhibits good cementitious properties and has a specific gravity of 2.85.

3) Fine Aggregate and Coarse Aggregate

The fine aggregate used in this work consisted of natural river sand conforming to IS: 383–2016 grading requirements. The sand was free from clay lumps, organic matter, and other deleterious impurities. Its particle size distribution satisfied the criteria for Zone II, ensuring good workability and cohesive behaviour in SCC mixes. Fine aggregate plays a crucial role in providing smooth flowability and filling ability in self-compacting concrete. Properties are shown in Table 1.

Crushed angular coarse aggregates of 10 mm nominal size were used, meeting the specifications of IS: 383–2016. The aggregates were clean, hard, and free from dust or flaky particles to ensure strong interlocking and reduced void content. Their angular shape enhances mechanical strength and contributes to the overall stability of the concrete matrix. Properties are shown in Table 2.

4) Ceramic Tile waste powder

Ceramic Tile Waste Powder is produced by crushing and grinding discarded or broken ceramic tiles generated from construction and manufacturing units. The tiles are initially cleaned, dried, and then pulverized into a fine powder to achieve cement-like fineness. CTWP is rich in silica and alumina, which contribute to its pozzolanic reactivity when mixed with cement. Its fine particle size improves packing density, reduces voids, and enhances the microstructure of concrete. Incorporating CTWP in SCC helps minimize environmental waste and reduces cement consumption, making it a sustainable material for high-strength applications.

5) Slag sand

Slag sand is a processed material obtained from the granulated slag generated during steel manufacturing. The slag is crushed, screened, and engineered to meet the grading requirements of fine aggregates. Slag sand particles are angular and have a rougher texture compared to natural river sand, which improves bonding and enhances the mechanical strength of concrete. It also reduces permeability due to its finer microstructure. The use of slag sand supports sustainable construction practices by reducing dependency on natural river sand and utilizing industrial by-products effectively. Properties are shown in Table 1.

Table I. Physical Characteristics of Fine aggregate and Slag sand

Property	Fine Aggregate	Slag sand
Fineness modulus	2.867	2.73
Zone	II	II
Bulk density (Loose)	1585KN/m^3	1300 KN/m^3
Bulk density(Compacted)	1674 KN/m^3	1510 KN/m^3
Specific Gravity	2.68	2.7

Table II. Physical characteristics of Coarse aggregate

Property	Coarse aggregate
Fineness modulus	4.20
Specific Gravity	2.86
Water absorption	1.0%
Crushing value	11.23%
Impact value	11.3%
Elongation index	20.34%
Flakiness index	16.95%

6) Superplasticizer

CERA Hyper Plast XRW-40 is a high-range water-reducing admixture based on polycarboxylate ether (PCE) technology. It is formulated to provide excellent dispersion of cement particles, resulting in superior flowability and workability essential for Self-Compacting Concrete. This admixture improves slump flow, reduces water demand, and enhances the cohesiveness of the mix without causing segregation. CERA XRW-40 complies with IS 9103 and is particularly suitable for producing high-strength, dense, and durable SCC mixes.

IV. MIX PROPORTIONS

Mix proportions for the reference SCC mix (M0) of M60 grade were designed as per EFNARC and IS:10262 guidelines. The control mix consisted of 80% cement, 20% GGBS, fine aggregate, coarse aggregate, water, and superplasticizer. Ceramic tile waste powder (CTWP) was used as a partial replacement for cement at levels of 5%, 10%, 15%, and 20%**.** After determining the optimum CTWP percentage, fine aggregate was partially replaced with slag sand at 10%, 20%, 30%, and 40%**.** A constant dosage of 1.4% Cera Hyper Plast XRW40 was used in all mixes. The various mixes used in the experimental program are listed in Table 3**.**

Table III Various Mix proportions of SCC

Mixes Designation	Cement kg/m^3	GGBS kg/m^3	CTWP kg/m^3	Fine Aggregate kg/m^3	Slag sand kg/m^3	Coarse aggregate kg/m^3	Water kg/m^3	SP in %
M0(Referencemix)	450	112.5	-	937.5	-	694.2	180	1.4%
M1(5% of CTWP)	427.5	112.5	22.5	937.5	-	694.2	180	1.4%
M2(10% of CTWP)	405	112.5	45	937.5	-	694.2	180	1.4%
M3(15% of CTWP)	382.5	112.5	67.5	937.5	-	694.2	180	1.4%
M4(20% of CTWP)	360	112.5	90	937.5	-	694.2	180	1.4%
M5(10%of CTWP+ 10% of Slag sand)	405	112.5	45	843.75	93.75	694.2	180	1.4%
M6(10%of CTWP+ 20% of Slag sand)	405	112.5	45	750	187.5	694.2	180	1.4%
M7(10%of CTWP+ 30% of Slag sand)	405	112.5	45	656.25	281.25	694.2	180	1.4%
M8(10%of CTWP+ 40%of Slag sand)	405	112.5	45	562.5	375	694.2	180	1.4 %

V. FRESH PROPERTIES

Fresh Properties of SCC are conducted i.e., Slump flow, L-Box, V-funnel. All ranges are according to EFNARC. Typical ranges include slump flow(550-850mm), L-Box(0.8-1.0) and v-funnel (8-25 seconds).

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Table IV Fresh properties of various SCC mixes

Mixes Designation	Slump flow(mm)	L-Box	V-funnel(seconds)
M0(Referencemix)	700	0.97	10
M1(5% of CTWP)	690	0.96	12
M2(10% of CTWP)	670	0.94	15
M3(15% of CTWP)	650	0.91	18
M4(20% of CTWP)	640	0.90	20
M5(10%of CTWP+ 10% of Slag sand)	660	0.89	16
M6(10%of CTWP+ 20% of Slag sand)	650	0.87	17
M7(10%of CTWP+ 30% of Slag sand)	640	0.86	18
M8(10%of CTWP+ 40%of Slag sand)	630	0.84	20

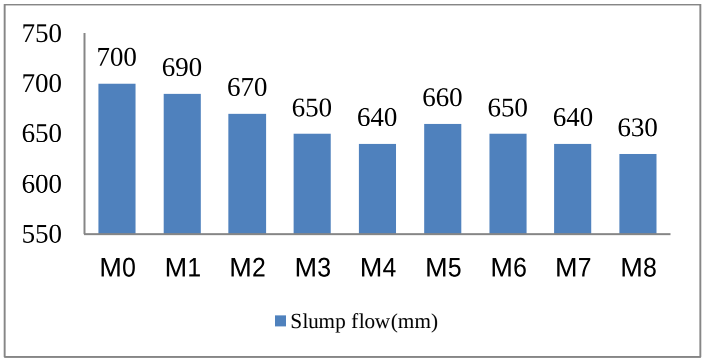


Fig I Graphical representation of Slump flow

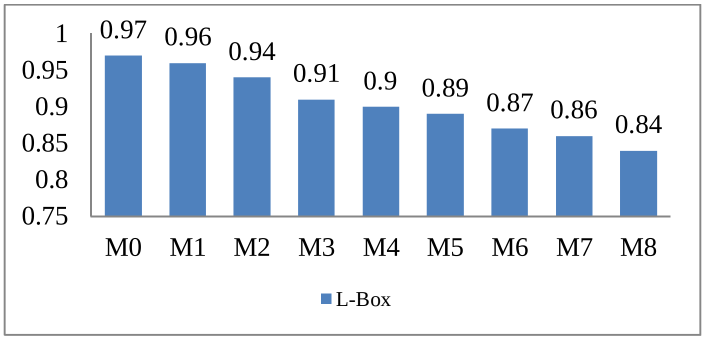


Fig II Graphical representation of L-Box

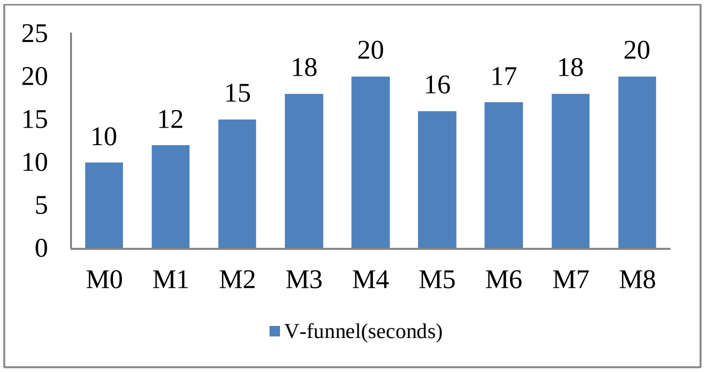


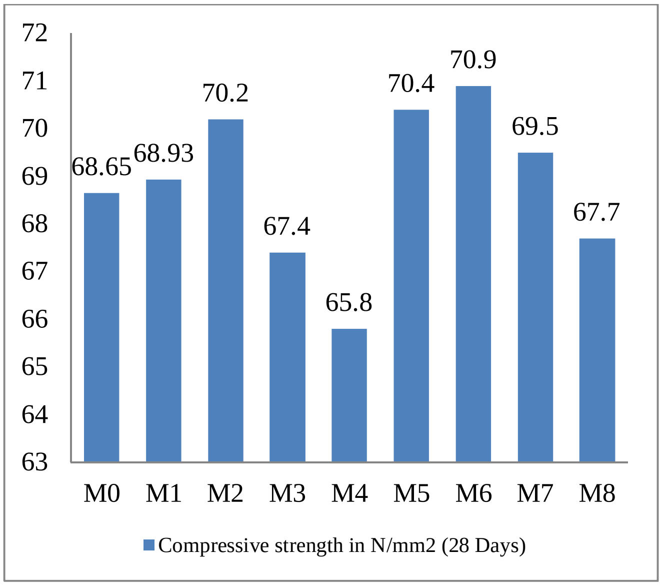
Fig III Graphical representation of V-funnel

VI. MECHANICAL PROPERTIES

Concrete specimens were cast to evaluate the mechanical properties of all SCC mixes. Cubes of 100 × 100 × 100 mm were prepared for compressive strength, cylinders of 100 × 200 mm were cast for split tensile strength, and beams of 100 × 100 × 500 mm were used to determine flexural strength. All specimens were cured for 28 days, after which the respective mechanical tests were conducted. The results of compressive, split tensile, and flexural strength for each mix are presented in Table 4**.**

Table V.Mechanical properties of various Mix proportions of SCC

Mixes Designation	Compressive strength in N/mm^2 (28 Days)	Split tensile strength in N/mm^2 (28 Days)	Flexural strength test in N/mm^2 (28 Days)
M0(Reference mix)	68.65	4.74	5.67
M1(5% of CTWP)	68.93	4.79	5.78
M2(10% of CTWP)	70.2	4.82	6.02
M3(15% of CTWP)	67.4	4.67	5.61
M4(20% of CTWP)	65.8	4.42	5.42
M5(10%of CTWP+ 10% of Slag sand)	70.4	4.89	6.05
M6(10%of CTWP+ 20% of Slag sand)	70.9	4.93	6.12
M7(10%of CTWP+ 30% of Slag sand)	69.5	4.65	5.79
M8(10%of CTWP+ 40%of Slag sand)	67.7	4.48	5.48



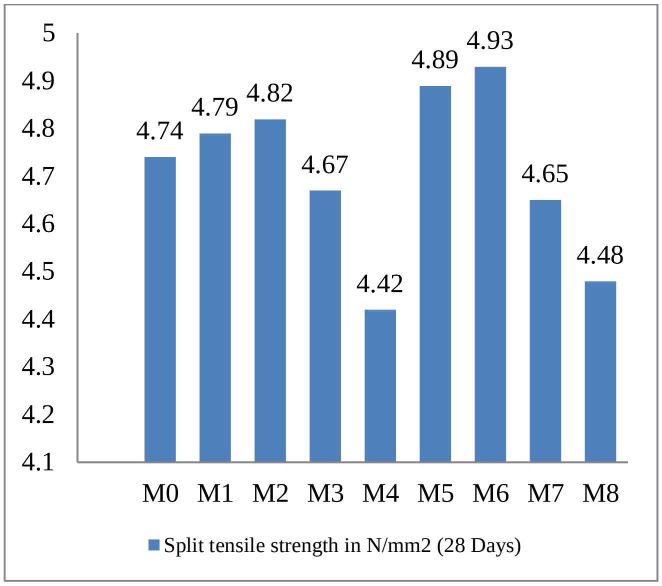


Fig IV Graphical representation of compressive strength   Fig V. Graphical representation of split tensile strength

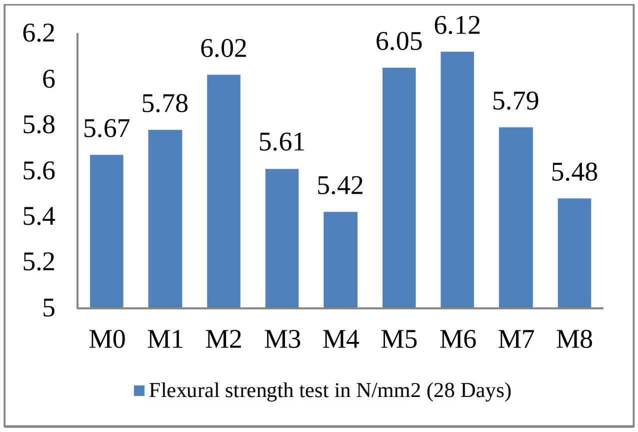


Fig VI. Graphical representation of flexural strength

VII. CONCLUSIONS

1) Mix M2 (10% CTWP) showed a 2.25% increase in compressive strength, a 1.68% rise in split tensile strength, and a 5.38% improvement in flexural strength compared to the reference mix. This confirms that controlled CTWP addition strengthens SCC by improving packing.
2) Mix M6 (10% CTWP + 20% slag sand) delivered the best performance among modified mixes with a 3.28% increase in compressive strength, 4.01% increase in split tensile strength, and a 9.97% rise in flexural strength over M0. Enhanced gradation and particle packing contributed to the improvement.
3) Strength improved for 5–10% CTWP, but mixes with 15–20% CTWP (M3, M4) showed declines in compressive strength by 1.82–4.15**%**, tensile strength drops of 1.47–6.75%, and flexural strength reductions of 0.96–4.41%**,** indicating reduced reactivity at higher ceramic content.
4) Slag sand replacements of 10–20% enhanced all mechanical properties, with M5 and M6 showing compressive strength gains of 2.55–3.28%**,** tensile strength increases of 3.16–4.01%**,** and flexural strength improvements of 6.91–9.97%**.** Beyond 30%, strength reductions occurred due to higher voids and reduced cohesiveness.
5) The best renewable mix (M6) exceeded the strength of control SCC in all categories—compressive (+3.28%), tensile (+4.01%), and flexural (+9.97%)—demonstrating that waste materials can successfully replace traditional constituents in SCC.
6) Workability remained within EFNARC limits for all mixes; however, mixes with 10% CTWP and 10–20% slag sand provided the best balance of flowability and viscosity.

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