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Optimizing strength and durability of concrete through GGBFS replacement and SAP inclusion

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ABSTRACT

The research explores M20 grade concrete performance upgrades through combination methods of cement replacement with ground granulated blast furnace slag (GGBFS) and internal curing usage of superabsorbent polymer (SAP). A combined mix of GGBFS replacing 10% cement content and SAP added at 0.1% and 0.2% and 0.3% weights of cement was used in this research. The research evaluation included testing compressive strength together with flexural strength and Rapid Chloride Penetration Test (RCPT) and carbonation resistance tests. When GGBFS was combined with 10% replacement rate and SAP content set at 0.3% the concrete mixture showed 9% stronger compressive strength and 11% better flexural strength than the standard concrete mix ratio. Internal curing properties of SAP showed effectiveness in minimizing shrinkage behaviour and restricting microcracks thus suggesting potential benefits for improving crack resistance through crack arrest. The addition of GGBFS in concrete mixtures reduced hydration heat thus reducing the potential for thermal cracks when used for mass concrete applications. By using GGBFS the construction process achieved two sustainability goals: it lowered cement usage and produced reduced CO_2 emissions. The combined usage of GGBFS with plastic bags optimizes concrete structure retention while maximising its long-term durability so it can withstand harsh environmental conditions.

Keywords: Durable infrastructure concrete; GGBFS-based green concrete; SAP-modified internal curing; crack-resistant mix design; chloride and carbonation resistance.

1. INTRODUCTION

Concrete remains most widely used construction material globally due to their versatility, strength, and durability in structural application. However, the production of Ordinary Portland Cement (OPC) of primary binder in conventional concrete significantly contributes global CO_2 emission. Consequently, there is a growing emphasis on developing sustainable concrete alternatives that reduce carbon footprint without compromising essential mechanical and durability properties [1].

(GGBFS) a by-product of steel manufacturing process had gained attention an eco-friendly partial replacement of OPC. Incorporating GGBFS at optimal replacement levels enhances concrete durability by refining its microstructure which improves resistance chloride and sulphate attacks and contributes to long term strength development [2]. GGBFS replacement reduces the environmental impact of concrete production by lowering cement consumption and associated carbon emissions.

Simultaneously the use Super Absorbent Polymers (SAP) as internal curing agents has emerged as an effective strategy to mitigate shrinkage and enhance hydration in low water-to-cement ratio concrete mixture [3]. SAP particles absorb and gradually release water during the cement hydration process supporting continuous curing and reducing autogenous shrinkage [4]. Internal curing mechanism. significantly improves the toughness durability and crack resistance of concrete although SAP incorporation can introduce voids that require careful optimization of dosage and particle size [5].

While previous studies have extensively examined the individual effects of GGBFS or SAP on high-strength concrete above M20 grade limited research exists on their combined influence in moderate-strength

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concrete mixes such as M20 [6]. Understanding the synergistic interaction between GGBFS and SAP is crucial for developing sustainable concrete mixtures that balance mechanical performance, durability, and shrinkage control [7].

This study addresses this research gap by experimentally investigation the combined effects of 10% GGBFS partial cement replacement and varying SAP dosage (0.1%,0.2%,0.3%) on mechanical properties and durability performance of M20 grade concrete [8]. The finding aims to provide practical insights into optimizing sustainable concrete mix designs enhancing service life [9].

2. MATERIALS AND METHODS

2.1. Materials

2.2. Cement

The construction industry heavily relies on cement for its ability to bind materials uniquely. The substance plays an essential role in connecting aggregates to reinforcement which produces powerful structures with extended durability [10]. The main strength of cement lies in its strong resistance to compression which makes structures in civil engineering durable across different applications [11]. Table 1 contains the fundamental characteristics of cement while Figure 1 displays its visual representation according to research [12].

Figure 1: Cement.

Table 1: Properties of the cement.

S.NO	CEMENT	VALUES
1	Specific gravity (g/cm^3)	3.12
2	Bulk Density of cement (kg/m^3)	1400
3	Grade	OPC 53
4	CaO	60–67
5	SiO_2	17–25
6	Al_2O_3	3–8
7	MgO	0.5–4

2.3. Fine aggregate (M - sand)

Fine aggregates mainly consist of natural sand or finely crushed stone that include particles measuring under 300 microns in size [13]. Several elements determine the best grading of fine aggregates because these factors include concrete mix composition and construction style and coarse aggregate size [14]. The particular gravity level of sand particles determines concrete density which leads to enhanced material strength [15]. The research uses manufactured sand (M-Sand) as the chosen fine aggregate [16]. IS 383-1970 (Clause 4) establishes four sand zones that progressively get finer as the grading moves from Zone I to Zone IV [17]. The measurement of specific gravity together with bulk density evaluates the suitability of these aggregates according to IS: 2386-3 (1963) [18]. The fine aggregate characteristics studied in this research appear in Figure 2 and are displayed in detail through Table 2.

2.4. Coarse aggregate

Materials retained on the 4.75mm sieve comprise coarse aggregates made up of either uncrushed gravel and natural disintegration products or crushed gravel or stone [19]. The three rock classifications of aggregates fall under igneous sedimentary and metamorphic while parent rock attributes determine the final aggregate characteristics. The composition of coarse aggregates includes 85 to 100 percent passing through the specified sieve along with up to 25 percent retained on the next lower sieve [20]. The tests conducted for sieve analysis according to IS 2386-1963 (Part 1) verified compliance with IS 383-2016 [21]. The experimental study analysed the characteristics of the coarse aggregates outlined in Figure 3 where Table 3 presents a summary.

Figure 2: Fine aggregate.

Table 2: Properties of the fine aggregates.

S.NO	FINE AGGREGATE	M SAND
1	Specific gravity (g/cm^3)	2.64
2	Bulk Density of Aggregate (kg/m^3)	1650
3	Water Absorption	2.5
4	Grading Zone	Zone II

Figure 3: Coarse aggregate.

Table 3: Properties of the coarse aggregates.

S.NO	COARSE AGGREGATE	GRAVEL
1	Specific gravity (g/cm^3)	2.71
2	Bulk Density of Aggregate (kg/m^3)	1700–2000
3	Water Absorption	1.17

2.5. Ground granulated blast furnace slag (GGBFS)

As a manufacturing byproduct GGBFS emerges when blast furnaces produce iron and steel materials. GGBFS maintains high value in construction due to its environmental benefits and technical properties when employed in concrete applications [22]. Concrete obtains sustainable characteristics when GGBFS serves as cement's environmentally friendly substitute to lower construction carbon emissions and use less cement thus reducing factory emissions linked to cement making [23].

GGBFS demonstrates a unique trait which consists of low heat of hydration lower than typical Portland cement [24]. The low heat of hydration in concrete minimizes stress buildup during heating that protects massive concrete structures including foundations and slabs against potentially harmful breaking [25]. The incorporation of GGBFS in concrete materials creates materials with reduced permeability which blocks destructive substances from penetrating and prolongs the useful life of concrete structures [26].

GGBFS functions as a substitute for Portland cement while filling part of its composition. The cement replacement through GGBFS leads to better concrete mix workability which makes concrete handling and placement operations easier [27]. The initial strength gain of GGBFS-based concrete happens more slowly than ordinary Portland cement concrete but it achieves better long-term strength particularly after 28 days [28]. The long-term structural requirements make GGBFS a perfect material selection for various applications [29]. A summary of GGBFS properties according to Table 4 is depicted in Figure 4.

2.6. Super absorbent polymer (SAP)

Contemporary research investigates the use of Superabsorbent polymers (SAP) in concrete technology because these polymers enhance concrete structures while boosting their sustainability performance [30]. Superabsorbent polymers have the ability to hold and retain large amounts of water compared to their original weight. The main purpose of using SAP in concrete applications involves acting as an internal curing agent [31]. SAP particles in cement mixing absorb water that later releases during cement hydration to sustain internal moisture balances and support complete hydration processes especially in thick sections that typically receive poor external curing [32].

Figure 4: (GGBFS).

Table 4: Properties of the (GGBFS).

S.NO	GGBFS	VALUES
1	Physical form	Off - white
2	Specific gravity (g/cm^3)	2.88
3	Bulk Density of GGBFS (kg/m^3)	1300
4	CaO	30–35
5	SiO_2	32–35
6	Al_2O_3	18–20
7.	MgO	10–12

The controlled internal curing procedure reduces initial cracking and enhances the durability characteristics across the concrete structure [33]. The success of SAP-modified concrete depends heavily on both proper measurements during the mixing phase and complete uniformity of particle distribution in the mixture [34]. SAP should be added to cement mixes at levels ranging from 0.1% up to 0.5% according to project requirements. SAP was added dry and absorption capacity in deionized water is 300–500 times its own weight [35].

SAP functions as embedded water containers that preserves cement matrix water content which leads to improved concrete resistance in harsh environments [36]. The incorporation of SAP into concrete improves resistance to freeze-thaw cycles because the polymer controls pore structure and protects against water expansion during freezing temperature fluctuations [37]. The essential properties of SAP are described in Table 5 with Figure 5 serving as an illustrative representation [38].

2.7. Mix design

Different proportions of M20 concrete mixes were developed through the combination of Super Absorbent Polymer (SAP) with (GGBFS) in multiple formulations [39]. The mix ratios consisted of individual SAP and GGBFS percentages starting from 0.1% SAP with 10% GGBFS up to different proportions. The series of mix ratios employed (0.2%, 10%) and (0.3%, 10%) as percentage combinations of SAP and GGBFS. The different mixtures combining coarse aggregate with fine aggregate and SAP and GGBFS were analysed to determine their effects on concrete mechanical properties.

All materials were properly mixed for full combination until the SAP solution was progressively added over time for preventing clumps. Lower dosage of SAP 0.1% leads to optimized pore structure where beneficial internal curing effects dominates whereas higher dosage of 0.2% causes excessive porosity and voids impairing the strength. The concrete mix received continuous blending until the fibres and additives showed complete distribution throughout the entire material. Because of this careful systematic mixing process and curing method researchers obtained consistent mechanical property assessment conditions for all mix designs. The researchers systematically altered SAP and GGBFS proportions to discover the best mixture which improved concrete strength along with performance and durability for structural implementation [40].

2.8. Methods

A designed mixing technique guides the combination of M20 grade concrete with different SAP and GGBFS content levels into the concrete matrix.The formulated blends consist of mixtures containing SAP at 0.1%, 0.2%,

Figure 5: Super Absorbent Polymer (SAP).

Table 5: Chemical properties of super absorbent polymer (SAP).

PROPERTIES	VALUES
FORM-DRY	Crystalline white powder /granules
FORM-WET	Transparent gel
Particle Size	0–1 mm
Density	1.08
Bulk Density	0.85
Available Water	95% approx.

Table 6: Mix proportion.

MIX ID	CEMENT (%)	GGBFS (%)	SAP (%)	WATER (%)	FINE AGGREGATE (%)	COARSE AGGREGATE (%)
Mix 1	70	10	0.1	15	30	45
Mix 2	69.8	10	0.2	15	30	45
Mix 3	69.7	10	0.3	15	30	45

and 0.3%, each combined with 10% GGBFS. Scientists examined these particular ratios to determine their effects on concrete mechanical properties.

Manufacturing of concrete starts with the selection and proper preparation of cement and fine aggregates followed by water addition and application of the selected fibres. The mix design development for SAP and GGBFS modified concretes remains an unestablished field so researchers depend on adapted volumetric methods from previous studies. SAP and GGBFS enter the mixture during the mixing process in controlled increments to obtain full distribution within the concrete mass thus improving its ductility and its resistance to cracking.

After blending the components researchers perform mechanical tests including compressive strength testing as well as flexural strength testing and durability assessments for performance evaluation. Changes in structural applications' durability targets and desired mechanical properties and serviceability demands can be achieved through evaluations which lead to identifying proper SAP and GGBFS percentage amounts. The blending process for SAP and GGBFS addition demonstrates a complete methodical procedure dedicated to creating strong concrete formulations that fulfill multiple engineering requirements.

2.9. Specimen characteristics (Cube)

The concrete samples made with SAP and GGBFS are moulded into cube shapes with exact dimensions of 150 mm × 150 mm × 150 mm for strength evaluation. A few concrete cubes need to be prepared according to strict procedures, which are intended to guarantee both accuracy and consistent results. The testing of compressive strength occurs at crucial curing periods, starting from 7 days and ending at 28 days after the casting process. The testing methodology includes a two-stage analysis that delivers critical information about concrete strength at initial development stages as well as extended performance. The examinations of test specimens at different time points allow researchers to obtain complete information about material behaviour and its progressive strength development. A depiction of the specimen after preparation is shown in Figure 6.

Figure 6: Casting of cube.

2.10. Specimen characteristics (Prism)

Prism-shaped specimens determine the flexural strength of concrete that contains SAP combined with GGBFS. The testing of flexural strength takes place through two essential curing stages which begin with 7 days but continue until 28 days after casting. The specimens follow precise dimensions at 500 mm × 100 mm × 100 mm. Two-stage testing methodology enables comprehensive strength analysis of concrete as it progresses between 7 days and 28 days from casting time. The test specimen is shown below in Figure 7.

3. TESTING OF SPECIMEN

3.1. Compressive strength test

The research data shows concrete achieves higher compressive strength when SAP and GGBFS are added together. The test findings demonstrate how SAP together with GGBFS affects concrete compressive strength within different curing periods. The test data shows that concrete strength values rise when SAP proportion increases for measurements at 7, 14 and 28 days curing time[41]. Mix M3 demonstrates superior compressive strength across all curing stages because it encompasses 0.3% SAP content which makes it stronger than Mixes M1 and M2. In contrast, Mix M2, incorporating 0.2% SAP, records relatively lower strength results. The test results demonstrate how the incorporation of SAP creates better concrete strength values throughout the curing period. Research data serves a vital purpose for developing superior concrete mixture designs that fulfill the requirements of different structural behavioural needs across construction sites. The specimen used in this evaluation is shown in Figure 8.

Figure 7: Casting of prism.

Figure 8: Compressive strength test.

3.2. Flexural strength test

The concrete mix flexibility increased substantially when Mix M1 was added SAP and GGBFS when compared to Mixes M2 and M3. The strength improvement of concrete against tensile and splitting forces depends largely on the presence of GGBFS and SAP as additives. Flexural strength of Mixes M1 and M3 surpassed that of Mix M2 because they included SAP together with GGBFS. The strength results of Mix M2 with its 0.2% SAP amount match those of Mix M3 with its 0.3% SAP despite having a lower composition of SAP. The additional reinforcement capabilities of GGBFS continued to activate benefits when mixed with lower amounts of SAP in the concrete structure. All tested mixes demonstrated regular strengthening of flexural strength as curing time extended, because concrete typically gains strength throughout maturation [42]. This assessment utilizes the Figure 9 specimen, which is shown in the images below.

Figure 9: Flexural strength test.

3.3. Carbonation test

Atmospheric CO_2 penetrates concrete through its porous surface and lowers pH levels to 8 or 9 until it ends the protection on reinforcement bars. The initial stage of carbonation starts when atmospheric CO_2 meets concrete pore water to create carbonic acid (H_2CO_3) while the subsequent phase activates the carbonic acid to convert calcium hydroxide [Ca $(OH)_2$] into calcium carbonate ($CaCO_3$). The pH value in pore solution falls from 12.5–13.5 to 8–9 causing reinforcement de-passivation and the start of corrosion processes. carbonation test exposure conditions for CO_2 concentration 20%, temperature 20°C ± 2°C and humidity 70% ± 5%, duration of 28 days. The deterioration process of embedded steel in concrete structures develops mainly due to carbonation conditions together with moisture content and oxygen exposure.

The measure of carbonation assessment focuses on determining carbonation penetration depth. Various qualities affecting the carbonation rate include concrete grade classification, its permeability level and whether coatings are present along with the depth of concrete cover and the duration of exposure. The 1% phenolphthalein solution in ethanol serves as the indicator solution for this test by dissolving 1 gram of phenolphthalein powder in 100 millilitres of a prepared solution made from 70 ml ethanol and 30 ml deionized water. The test requires examination of brand-new concrete materials that come from fresh pieces obtained by breaking concrete or split tests performed on concrete core samples. Testing requires splitting the core unless this method is unfeasible so surface-drying and sealing the core becomes necessary to prevent carbonation before measurement [43]. The surface needs cleaning from dust and loose particles before the indicators solution application is possible. A stable reading develops from the indicator solution between 5 to 10 minutes after application. Keep applying the indicator solution again after the surface has dried when its initial colour appearance is faint or non-existent.

The diagnostic evaluation of concrete based on carbonation requires extraction steps followed by pH indicator usage or alternative chemical applications to assess the penetration depth. The necessary performance standards for concrete durability can be evaluated through these tests because they determine environmental resistance capabilities. The attached experimental concrete specimens is shown in Figure 10.

Figure 10: Carbonation test on prism and cube.

3.4. Rapid chloride penetration test (RCPT)

Reinforced concrete assessment for chloride ion protection relies on the standardized method known as the Rapid Chloride Permeability Test (RCPT) as outlined in ASTM C1202. The presence of chloride ions which either come from de-icing materials or marine sources stands as the main reason behind steel reinforcement corrosion in concrete structures. The RCPT measures chloride penetration rate to provide essential information about how well the concrete maintains embedded steel protection from corrosion. The results measured during RCPT testing demonstrate strong similarity with those produced by conventional 90-day salt ponding tests. The standard test procedures for the RCPT appear in AASHTO T 277[44] and ASTM C1202 [45].

During this evaluation procedure researchers monitor the total electrical charge that moves through a concrete test specimen which normally consists of a 100 mm diameter and 50 mm thick segment throughout six hours of testing. The test requires concrete samples which come from either cores or standard concrete cylinders. A 60V DC voltage operates between testing solutions during the process where one side immerses in 3% NaCl solution while the opposing side enters 0.3M NaOH solution. The electrical current measured reflects the overall ion movement within the pore structure of the concrete, not exclusively the chloride ions. The test outcomes might become unclear due to supplementary cementitious materials like fly ash, silica fume, or ground granulated blast-furnace slag (GGBFS) as well as chemical admixtures such as water reducers, superplasticizers, or corrosion inhibitors present in concrete samples. For this study, RCPT was conducted on 28-day-old concrete samples [46]. The chloride permeability rates for the tested concretes are summarized in Table 7, and the associated test specimens are illustrated in Figure 11 and Figure 12.

Table 7: Rating of chloride permeability and concrete.

CHARGES (COULOMBS)	CHLORIDES PERMEABILITY
>4000	High permeable concrete
2000–4000	Moderate
1000–2000	Low
100–1000	Very Low
<100	Negligible

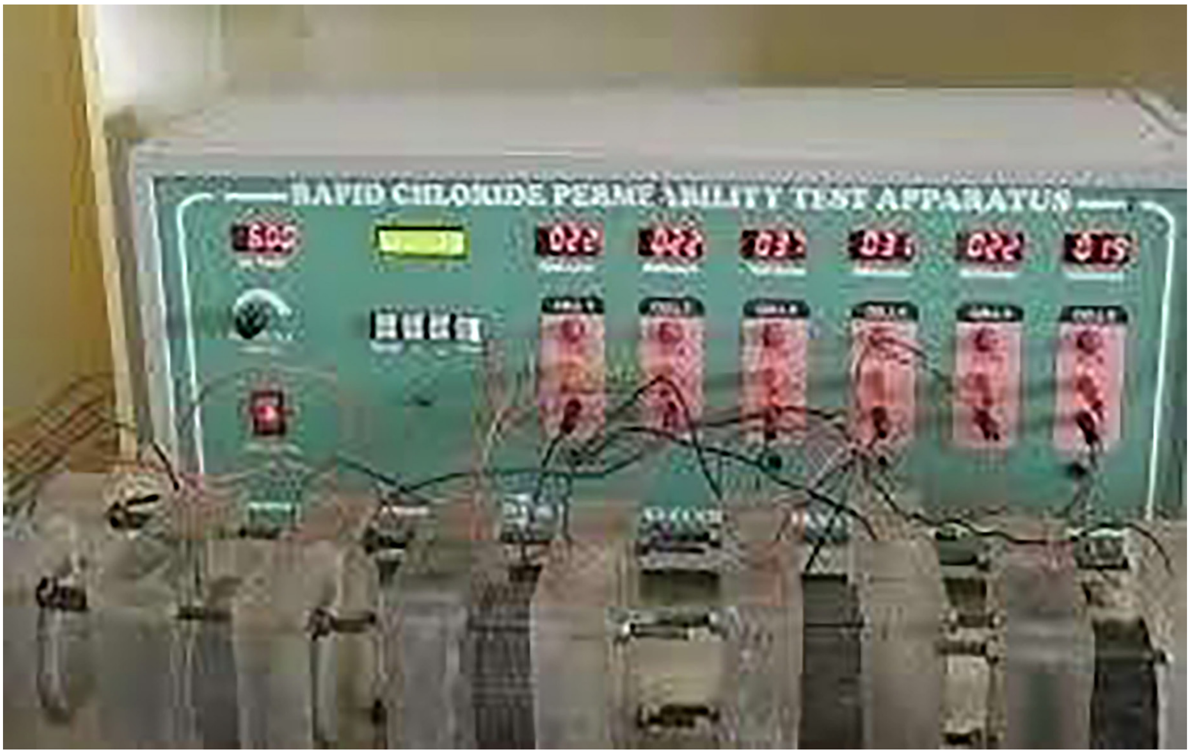

Figure 11: RCPT apparatus.

Figure 12: RCPT on cylinders.

4. RESULTS AND DISCUSSIONS

4.1. Compressive strength results

A compressive strength test was performed on 9 concrete cubes containing various proportions of SAP and GGBFS to determine their resistance values. The researchers tested the developed cubes after they underwent curing for periods of 7, 14, and 28 days. Table 8 provides the complete data regarding the compressive strength measurements.

The prepared concrete samples contained M1 mix proportions of 90% cement with 10% GGBFS and aggregates and 0.1% SAP resin along with water content while M2 mix contained 90% cement with 10% GGBFS and aggregates and 0.2% SAP with water content and M3 mix had 90% cement with 10% GGBFS and aggregates with 0.3% SAP and water content. The various concrete mixes underwent compressive strength testing after different curing periods where Table 8 displays the obtained results. Tests show that as the SAP content within concrete rises so do the compressive strength measurements during 7, 14 and 28 days of curing periods. All testing periods demonstrate that Mix M3 obtains superior strength despite its 0.3% SAP concentration surpassing Mixes M1 and M2. The combination of cement materials and 0.2% SAP in Mix M2 produces minimal compressive strength measurement results. The research findings demonstrate that SAP acts as a beneficial ingredient for concrete compression strength growth particularly in longer curing durations. The research findings help improve mix design specifications to fulfill strength targets necessary for different construction projects as depicted in Figure 13.

4.2. Flexural strength of concrete

M1 received a mix solution containing 90% cement combined with 10% GGBFS along with aggregates and 0.1% SAP (high water-absorbing poly (sodium acrylate) resin) and water whereas M2 employed 90% cement and 10% GGBFS along with aggregates and 0.2% SAP before adding water and M3 incorporated 90% cement together with 10% GGBFS and aggregates mixing with 0.3% SAP and water. The results showed Mixes M1 and

M3 outperformed Mix M2 in terms of flexural strength together with flexibility. The results indicate that concrete flexural strength shows substantial enhancement when GGBFS and SAP are used together as ingredients. The flexural strength results of M1 matched those of M2 even though M1 contained fewer SAP contents during all curing days. Table 9 provides the complete data regarding the flexural strength measurements.

Concrete performance improvements could be obtained through the addition of SAP to GGBFS even when both substances are used at lower relative ratios. The test data contained in the table verifies that concrete obtains higher splitting tensile strength when both GGBFS and SAP are incorporated. The research results for flexural strength appear in Figure 14 as a graphical presentation.

4.3. Carbonation test results

Atmospheric carbon dioxide enters concrete porosity to cause pH value reduction which is known as carbonation. A high pH environment above 10 will produce bright pink colour changes during indicator solution application. The concrete quality evaluation becomes possible through a pH measurement decrease below 10 which leads to visible colour changes. The carbonation testing of prisms and cubes using various mix proportions took place at 14 and 28 days post-curing. The assessment of carbonation depths from the different mix combinations using SAP and GGBFS in various concentrations appears in Table 10. When the SAP content increased

Table 8: Compressive strength of concrete.

S.NO	DESCRIPTION	COMPRESSIVE STRENGTH (N/MM2) AT 7 DAYS	COMPRESSIVE STRENGTH (N/MM2) AT 14 DAYS	COMPRESSIVE STRENGTH(N/MM2) AT 28 DAYS
1	OPC(M20)	14.26	20.15	26.28
2	M1(0.1%)	17.12	21.82	29.89
3	M2(0.2%)	15.84	19.28	27.11
4	M3(0.3%)	19.33	22.92	31.48

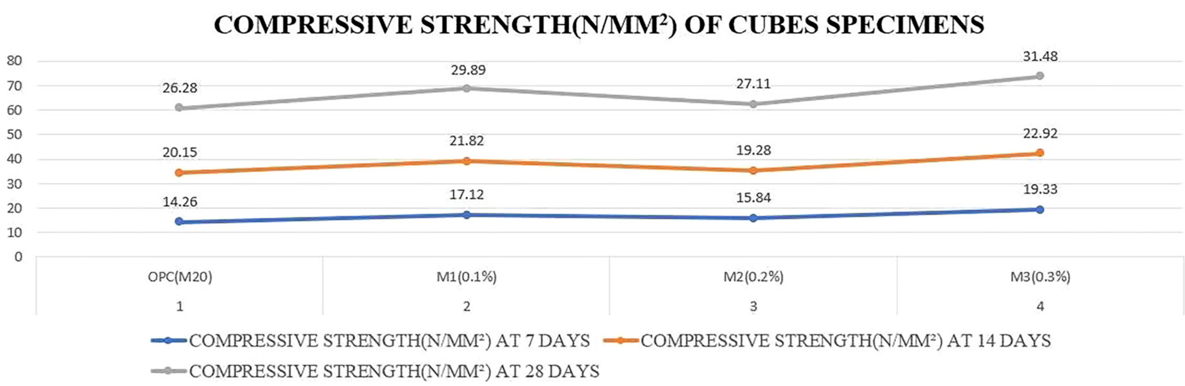

Figure 13: Compressive strength for 28 days.

Table 9: Flexural strength of concrete.

S.NO	DESCRIPTION	FLEXURAL STRENGTH(N/MM2) AT 7 DAYS	FLEXURAL STRENGTH(N/MM2) AT 14 DAYS	FLEXURAL STRENGTH(N/MM2) AT 28 DAYS
1	OPC(M20)	2.38	2.89	3.28
2	M1(0.1%)	3.42	4.56	5.23
3	M2(0.2%)	2.89	3.68	4.04
4	M3(0.3%)	3.62	4.97	6.87

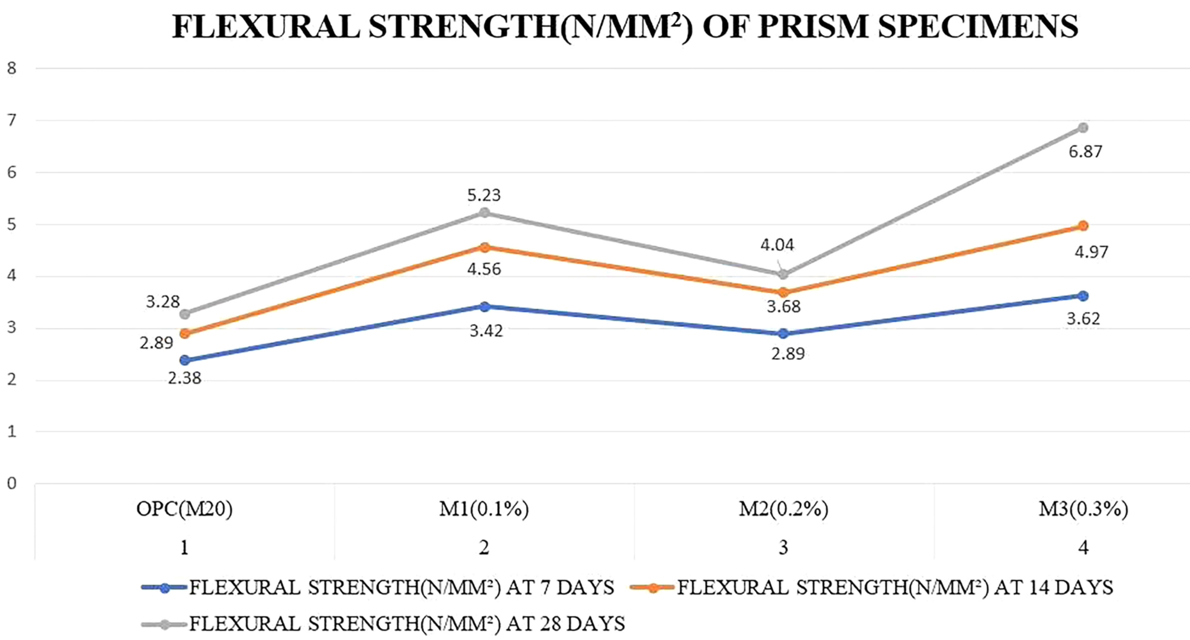

Figure 14: Flexural strength for 28 days.

Table 10: Carbonation depth of concrete.

S.NO	DESCRIPTION	CARBONATION TEST AT 14 DAYS(MM)	CARBONATION TEST AT 28 DAYS(MM)
1	OPC(M20)	4.08	6.35
2	M1(0.1%)	2.45	4.78
3	M2(0.2%)	3.46	5.18
4	M3(0.3%)	3.89	5.37

Figure 15: Carbonation depth on cube.

throughout the mixtures the carbonation depth rates rose during both curing periods. Mix M3 achieved maximum carbonation depths among all mixes at 14 days and 28 days since it contained a maximum SAP content of 0.3% when compared to Mixes M1 and M2. The carbonation depths of Mix M2 remained at reduced levels compared to the other mixtures because it contained 0.2% SAP. The C-O characteristic peak which matches $CaCO_3$ content showed a reduction as carbonation depths kept increasing. The C–O absorbance values reach stabilization because carbonates exist in the aggregates. The study conducted to measure carbonation depth uses the specimens depicted in Figure 15.

4.4. Rapid chloride penetration test (RCPT) results

The Rapid Chloride Penetration Test (RCPT) examines concrete resistance to chloride ion penetration for predicting longevity and durability of structural concrete elements. The testing apparatus contains two separate reservoirs for holding 3% NaCl and 0.3 M NaOH solutions. An analysis requires a 50 millimeter thick concrete sample with 90 to 100 millimeter diameter. Table 11 presents the results obtained from the RCPT measurements on different concrete mixtures and these data points appear in Figure 16 visually.

Table 11: RCPT of concrete.

S.NO	DESCRIPTION	7 DAYS CHLORIDE PENETRATION		28 DAYS CHLORIDE PENETRATION	
		COULOMBS	REMARKS	COULOMBS	REMARKS
1	OPC(M20)	2568	M	1784	L
2	M1(0.1%)	1574	L	1145	L
3	M2(0.2%)	984	V.L	867	V.L
4	M3(0.3%)	1289	L	912	V.L

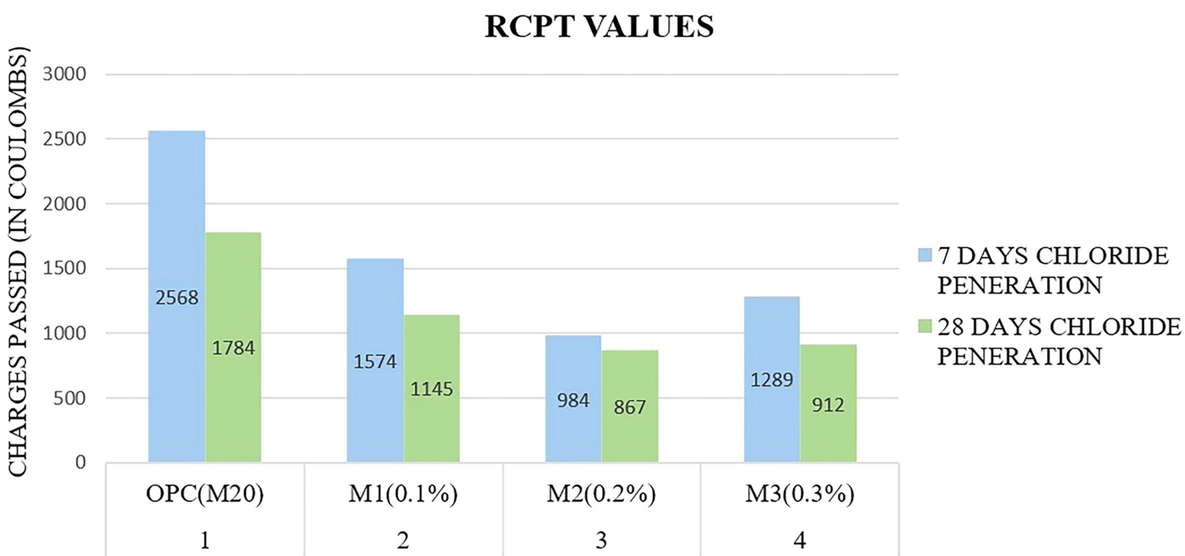

Figure 16: RCPT at 28 days.

5. CONCLUSION

The research produces multiple critical findings. When GGBFS replaces 10% of cement and SAP dosage ranges from 0.1% to 0.3% it results in concrete strength increases over traditional cement mixes. The use of 0.3% SAP leads to compressive strength improvements by 9% and flexural strength increases by 11%. Research shows that very minimal amounts of SAP generate noticeable improvements in key mechanical traits of concrete. Achieving the best utilization of SAP technology produces durable concrete structures as well as shrinking control and reduced cracking behaviour. SAP added concrete may have slightly lower early strength than conventional concrete due to internal voids. It offers better durability by reducing shrinkage, cracking and improving long-term performance through internal curing. The incorporation of GGBFS creates favourable effects because steel manufacturers generate GGBFS as a residue while its implementation reduces cement production associated with considerable carbon emissions. As GGBFS enters concrete structures it helps decrease the heat of hydration so thermal stresses become manageable particularly when handling big concrete pours.

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