Analyzing the Impact of Supplementary Cementitious Material and Polypropylene Fiber on the Fresh, Mechanical Properties, and Acid Attack of Quaternary Blended Self Compacting Concrete

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Abstract: Self-Compacting Concrete (SCC) is defined as concrete that has an ability to flow under its own weight, to fill the required space or formwork completely and to produce a dense and adequately homogenous material without a need for vibrating compaction. This study aims to develop an inexpensive SCC and reduce waste and carbon emissions from cement manufacturing by adjusting the fly ash and GGBS concentration and substituting 10% silica fume for 50% of cement. Additionally, tests were carried out on (0.2%) polypropylene fiber (PPF) in SCC mixes to see whether it could impact the material's strength and durability. Super plasticizers were added to the regular SCC and QBSCC mixed concrete to improve their workability even more. In this study eight different mixes were prepared, four mixes with polypropylene fiber and four mixes without fibers. The fresh properties tests were conducted such as slump flow, T-50-time, J-ring, L box tests, U box tests, and V funnel tests, were carried out and results were compared. And Mix-2 and Mix-2PPF with polypropylene fiber showed superior fresh properties. The compressive strength, split tensile strength and flexural strength on the hardened state of scc was carried out. The conclusions are drawn based on the test results. Whereas Mix-4 without fiber and Mix-4PPF with polypropylene fiber demonstrated the best results. To examine the resistance of concrete specimens to aggressive sulfuric acid solutions. The specimens were cured for 7 and 28 days subjected to 15% of sulfuric acid for 28 days, based on the tests result conclusion were drawn.

Keywords: Quaternary Blended Self-Compacting Concrete (QBSCC), Silica Fume (SF), Ground granulated blast Furness slag (GGBS), Fly Ash (FA), Polypropylene Fiber (PPF)

1. INTRODUCTION For several years beginning in 1983, the problem of the durability of concrete structures was a major topic of interest in Japan. The creation of durable concrete structures requires adequate compaction by skilled workers. The designs of modern reinforced concrete structures become more advanced, the designed shapes of structures are becoming increasingly complicated and heavy reinforcing is no longer unusual. Furthermore, the gradual reduction in the number of skilled workers in Japan‟ s construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structure independent of the quality of construction work is the employment of self-compacting concrete, which can be compacted into every corner of a form work, purely by means of its own weight and without the need for vibrating compaction. Okamura proposed the necessity of this type of concrete in 1986. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, have been carried out by “Ozawa and Maekawa” at the university of Tokyo.

Cement is the backbone of global infrastructure development. In 1996, it was estimated that the global production of cement was about 1.3 billion tons. The production of every ton of cement emits approximately 0.87 tons of carbon dioxide. In other words, 7% of the world’s carbon dioxide emission is attributable to the Portland cement industry. Due to its significant contribution to environmental pollution and the high consumption of natural resources, such as limestone, we cannot continue to increase the production of cement. There is a need to economize the use of cement. One practical solution to economize cement is to replace cement with supplementary cementitious materials such as fly ash silica fume and slag. The addition of the supplementary cementitious materials (SCMs) like Fly Ash (FA), Silica Fume (SF), and Ground Granulated Blast Furnace Slag (GGBS) materials tends to reduce the atmospheric pollution caused by the manufacturing of cement. [1] The use of supplementary cementitious materials (SCMs), has been widely explored in concrete because of their pozzolanic properties and the potential to enhance concrete performance. These materials provide benefits such as reduced CO_2 emissions, enhanced workability, and improved long-term strength gain. Moreover, the addition of polypropylene fibre is intended to reduce the likelihood of cracks forming, increase tensile strength, and strengthen resistance to many types of deterioration, including shrinkage, chemical attacks, and freeze-thaw cycles. Comprehending the synergistic effects of mixing SCMs and fibres in SCC is crucial for optimising concrete mixtures that can endure extreme weather and increase the lifespan of concrete structures. Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and properties desired. The type and concentration of the acid, the concrete's composition, and the surrounding circumstances are some of the variables that affect how long concrete will withstand acid attack. Concrete can be weakened by more corrosive acids like sulfuric acid, but it is normally resistant to weak acids like those in rainfall. Many steps can be taken, such as applying coatings and chemicals that are resistant to acidity and maintaining the concrete according to recommended guidelines, to increase its resilience against acid assault. Additionally, you can increase the resistance of concrete against acid corrosion by choosing the right kind of concrete for a given area and making sure that the right construction methods are used [2] In this study, the durability characteristics of concrete are studied by acid attack. A number of studies have been conducted on the replacement of cement with SCMs to enhance the durability and mechanical properties of concrete the studies found that, the incorporation of mineral admixtures improved the filling and passing ability of SCCs but slightly increased the T500 slump flow time, Especially in silica fume-containing concretes. Concrete containing 10% FA and 10% SF achieved the highest compressive strength. [3] Assessment of optimal ratio between chemical and mineral admixtures plays a vital role in developing SCC. In the current study, three distinct mineral admixtures were utilized in varying ratios as a partial replacement for cement in order to produce SCC, which has a typical compressive strength of 60 MPa. The qualities of all three varieties of SCC, both fresh and hardened, were studied. Based on the findings, partial cement substitutes of 50% GGBFS, 10% SF, and 20% MK were determined to be the most suitable alternatives. [4] Self-compacted concrete (SCC) is cast in the formwork without compaction and it fulfils the formwork due to its own weight to further enhance the performance of SCC, different types of fibers are tried in order to produce fiber reinforced SCC. The concrete’s fibers improve its mechanical qualities by bridging cracks and delaying their growth. [5] hardened concrete specimens with different variables i.e., partial replacement of cement With RHA (0%, 5%, 10%, 15% and 20%), concrete aged (3, 7, 28, 90, 180, and 270 days), and water to binder ratio (0.38, 0.44, 0.50, 0.56, 0.62, and 0.68). Fresh concrete properties were measured by V-funnel flow time, L-box, and slump flow diameter and time tests. Mechanical properties were determined in terms of compressive strength, modulus of elasticity, splitting tensile strength, and compressive stress-strain relationship tests. [6] The hardened properties are tested under compressive strength after 3, 7, 14, 28 and 56 days, Split tensile strength after (28) days, flexural strength after (28) days, acid attack after (28 and 56) days, water permeability, and rapid chloride penetration. The compressive improved maximum increase was 11.6% by use (12) mm length fibers. The split tensile strength by use polypropylene fibers in self-compacting concrete was improved by maximum 17.8% as compared to without Polypropylene fibers with (12) mm lengths of fibers. Polypropylene fibers give better flexural resistance about 15.5% maximum at (12) mm length fibers, as well improvement in surface porosity and water permeability. [7] different mixing periods (e.g., 15, 30, 60, and 90 min from the addition of water to the mixture) and increased SP doses (e.g., 1.5%, 2%, 2.5%, and 3% of cement mass) on the properties of SCC mixtures. The properties of fresh concrete were assessed by Seven tests, namely, slump flow, V-funnel, slump flow T_{50}, V-funnel T_5, L-box, bleeding, and segregation. Hardened concrete was assessed on the basis of compressive, indirect, and flexural strengths. Results showed that compared with the slump flow under 15 min mixing time, the 30, 60, and 90 min increase in mixing time reduced slump flow by 6%, 19%, and 27%, respectively. Findings also showed that results of SCC segregation and bleeding decreased when increased mixing time. The results also appeared that compressive strength of SCC slightly decreased compared with that under 15 min mixing time. The increase in dosage of super plasticizer has mitigated the negative effect for long mixing periods on the properties of concrete. [8] The final test findings show that, compared to the control mix, hybrid concrete has a 13.42% increase in compressive strength after 28 days of curing. Additionally, after 28 days in an acidic environment, there is a minor loss in strength of 11.44%, compared to a decline of 17.92% in the control mix under the same conditions. SEM microstructural examination verifies the appearance of strength-enhancing substances such calcium silicate hydrate (C-S-H) and calcium alumino-silicate hydrate (C-A-S-H), which lead to the formation of dense microstructures. [9] in harden state Strength in Ultimate with replacement of Polypropylene fibres range 0% -1.5% in 0.5 interval and also the focusing of work with various percentage of fly Ash and GGBS combination and behaviour of fiber under loading, compression strength, Split Tensile Strength & Flexural Strength. [10] The literature review on acid attack of concrete reveals that the use of supplementary cementious materials such as fly ash ggbs and silica fume can enhance the acid attack. Cement was replaced with ground granulated blast furnace slag (GGBFS) (25%, 50% & 75%), Metakaolin (MK) (10%, 20% & 30%) and Silica Fume (SF) (5%, 10% & 15%) respectively. Durability studies such as resistance against acid attack, sulphate attack, water absorption and sorptivity were done to evaluate the suitability of mineral admixtures. Concrete submerged in Na2So4 solution did not significantly differ in weight loss. In comparison to the control SCC, SF with a 10% substitution and MK with a 20% substitution produced good outcomes. Therefore, it can be said that SCC could be created using additional cementitious elements without sacrificing its endurance. [11] Slump flow, J-Ring, V-funnel tests are conducted to justify the fresh properties of SCC and are checked. 150x150x150 mm cubes having a nano silica content of 1%, 1.5%, and 2% are among the 15 SCC cubes without nano silica, while the remaining 15 cubes have a nano silica content of 16%, 30%, and 16%, respectively. Axial compression tests were performed on cubes after 7 and 28 days of water curing, as well as immersion in 5% HCl and 5% H2SO4 to obtain a general understanding of the compressive strength and durability features of SCC. A sorptivity test has also been performed to evaluate SCC's durability. The results of the tests show that adding nano silica to SCC has enhanced both its strength and endurance. [12] samples with different percentage addition of ggbfs, fly ash and polypropylene fibres cured with Concentrated Sulphuric acid (H2SO4) and Sodium hydroxide (NaOH) at the period of 60, 80 and 120 days and it was tested under the temperature of 200'C and 400'C and it was tested for the compressive strength. Comparing the results with the samples without addition of polypropylene fibres (1% and 2%) there is a marked improvement in the compressive strength. [13], SCC is reinforced with steel fibers at varying percentages from 0 to 2.0 %. Marble waste as filler materials (10 % by weight of sand) was also added to improve the microstructure. The SCC is exposed to a 4 % sulfuric acid solution for a specified period. The results show that adding steel fiber and marble waste significantly enhanced the SCC's performance in an aggressive setting. Strength, durability, performance at high temperatures, and the microstructure of SCC are all positively impacted by the synergistic interaction of marble waste as filler and steel fiber as reinforcement. The addition of 1.5% steel fiber resulted in the greatest mechanical gain, with 10% and 20% greater compressive and tensile strength, respectively. Steel fiber also prevented sudden failure and allowed warning (cracks), which improved ductile failure. However, because of a lack of flow ability, a higher dose of steel fiber (beyond 1.5%) reduced the SCC performance. The investigation came to the conclusion that steel fiber should only be added in an amount of 1.5%. [14] On the prepared samples, mechanical, durability, and physical tests were performed. Following testing, it was determined that adding 3.5% of fiber and 20% of fly ash to cement boosted the concrete's compressive strength to 68 N/mm2. When the tested samples and regular concrete were compared, there was a nearly 30% difference in the strength aspect. According to SEM and XRD studies, adding fly ash to concrete results in its increased durability because it reacts with the available calcium hydroxide to form densified porosity, which reduces the thickness of the interfacial transition zone, the presence of more aluminium oxide in both the admixtures helps in maintaining the hardened nature, it also increases the compressive strength in the initial stage itself by reducing the formation of ettringite.[15]This study aimed to evaluate the performance of quaternary blended concrete by adding different percentages of fly ash GGBS and silica fume while reducing the cement content to fifty percent. To determine the flow properties, mechanical strength at different ages, and durability for various combinations of fly ash GGBS and silica fume, a total of eight mixes four mix with 0.2% fibers and four mixes without fiber were casted, and durability property particular emphasis on acid attack.

2. MATERIALS AND MIX COMPOSITIONS

According to IS: 269-2015 specifications, ordinary Portland cement (OPC) of grade 43, Ramco brand, has been utilised. As binders, silica fume, class F fly ash, and GGBS from the RMC facility were used, adhering to IS 15388.2003, IS:3812:2003, and IS 16714:2018 requirements. The specific gravity of OPC is 3.15 and for SF, GGBS, and FA were found to be 2.12, 2.91, and 2.16. Locally available crushed granite aggregates of 20mm down size and 12.5mm size down conforming to Indian Standard Specification was used as coarse aggregate for the present work. The physical properties of coarse aggregate are tabulated in Table 1, locally available M sand is used for all the mixes. The material was tested in accordance with the Indian standard code of practice and the results were found to satisfy the relevant specification. The physical properties of fine aggregates are listed in Table 2. Super plasticizer Glenium SKY 8233, manufactured by BASF Construction Chemicals (India) Pvt. Ltd. is used.

Table 1. Physical properties of coarse aggregate.

Sl.no	PROPERTIES	RESULTS
1	Specific gravity	2.62
2	Fineness modulus	8.79
4	Bulk density-compacted	1565 kg/ m^3

Table 2. Physical properties of fine aggregate

Sl.no	PROPERTIES	RESULTS
1	Specific gravity	2.65
2	Fineness modulus	3.28
4	Bulk density-compacted	1553 kg/m^3
5	Grading	Zone II

The fibers were incorporated as polypropylene type with a length of 12 mm and a diameter of 0.025-0.04 mm, as shown in Fig. 1, the fibers a specific gravity of 0.91. Fresh potable water was applied in all mixes to prepare the concrete samples.

Fig 1. Polypropylene fiber

Eight types of mix proportions were used, four mix incorporating 0.2% polypropylene fibers and rest excluding fibers. The self-compacting concrete (SCC) mix with and without fibers was formulated without any cement replacement, designated as Mix 1 and Mix 1PPF. Subsequently, cement was replaced with 10% silica fume, 30% FA, and 10% GGBS, labeled as Mix 2 and Mix 2PPF with and without fibers. Analogously, the cement replacements of 10% silica fume, 20% FA, and 20% GGBS, termed Mix 3 and Mix 3PPF for with and without fibers, respectively, were utilized in the third mix. Finally, the fourth mix substituted cement with 10% silica fume, 10% FA, and 30% GGBS, which was identified as Mix 4 and Mix 4PPF with and without fibers, respectively. The concrete mix code for samples with PPF indicates the addition of polypropylene fiber.

3. PREPARATION OF CONCRETE SPECIMENS AND TESTING METHODS

The concrete mixture was created in a pan mixer. The coarse and fine aggregates were first thoroughly blended, then cement and supplementary cementitious materials were added and mixed well to achieve a consistent colour. In the designs containing PP fibers, fibers are added, to the mix and mixed for 2 min. Subsequently, 60% water was added and the remaining water was mixed with super plasticizer and then added to the pan mix. After the mixing process was complete, necessary tests – Slump Flow, T500, J-ring V-Funnel, L-Box and U-Box – Test were conducted to determine the flow properties of the fresh QBSCC. The results of these tests are compared with the EFNARC requirements for SCCs. since it is a self-compaction concrete, the concrete flows under its own weight, so the moulds are not vibrated. After the concrete is demoulded, it is transferred to a curing tank. Then specimens are cured in water for 7, 28, and 56 days. Compressive, split tensile, and flexural strength tests are performed based, on the IS 516, requirements, the specimens were prepared to determine the strength of concrete. The durability properties of concrete were determined at 28days and 56 days. After the samples were cured for 7 ,28 and 56-day, cubes of size 150× 150 ×150 mm samples were tested for compressive strength and 150mm diameter 300 mm length cylindrical samples underwent tensile strength tests respectively, based on the IS 516. The flexural strength was calculated using, 100 × 100 × 500 mm beams. The acid attack was measured for 7 and 28 days of water curing subjected to 28days of sulfuric acid solution, the specimens were immersed in 15% of h2so4 for 28days, the specimens were allowed to surface dry before testing, and testing was undertaken in a laboratory at room temperature, and durability test were carried out on acid attack.

4. RESULTS AND DISCUSSION

4.1. Workability

The test results for Quaternary Blended Self-Compacting Concrete (QBSCC), both with and without fibers, reveal significant variations across crucial parameters. These parameters include slump flow, T500 time, V funnel time, L box ratio, and U box, as well as J ring slump.

4.1.1. Slump flow test T 500 mm slump flow time test and J- Ring test.

The slump flow value acts more as a qualifying factor of SCC than that of parameters derived from other tests, and slump flow values are classified into SF1, SF2, and SF3, respectively [EFNARC 2005]. Slump flow class SF1 (550–650 mm) is suitable for scarcely reinforced concrete structures such as housing slabs and tunnel lining works. SF2 (660–750 mm) is suitable for normal columns and wall concrete works. SF3 (760–850 mm) is suitable for congested reinforcement structures. The slump flow and T500 mm slump flow time values are presented in Table 3

The result indicates that substituting cement with mineral admixtures in concrete enhances its workability. However, the addition of polypropylene fibres reduces the concrete's rheological properties. Among the tested mixes, Mix-2, which comprises (50% OPC+10% SF+ 30% FA+ 10% GGBS), demonstrated the highest flow ability. This was evidenced by the highest slump flow measurements of 690 mm for Mix-2 and 675 mm for Mix-2PPF with fiber addition, along with the shortest T500 time of 3.1 seconds and 3.48 seconds respectively. This mix can be categorized as SF-2. [EFNARC].

Table 3. Flow Properties of QBSCC

MIX	Slump flow in mm	T_{500} time in seconds	J ring slump in mm	J ring h in mm
MIX-1	650	4.6	640	9
MIX-2	690	3.1	675	5
MIX-3	680	3.8	670	7
MIX-4	675	4	665	8
MIX-1PPF	590	6.26	530	14
MIX-2PPF	675	3.48	650	7
MIX-3PPF	640	4.63	610	10
MIX-4PPF	620	5.1	590	11

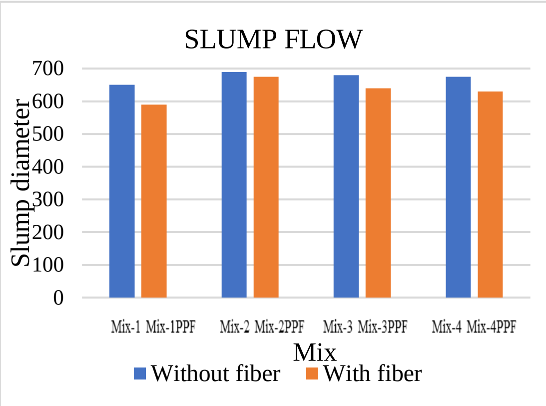

Fig 2. Slump flow of QBSCC

The quaternary blended SCC mixes can be classified differently according to the EFNARC 2005 guidelines, Mix 2, Mix 3, Mix 4, and Mix 2PPF fall under the SF2 class, while Mix 1, Mix 1PPF, Mix 3PPF, and Mix 4PPF are classified as SF1, and all mix are categorized as VS2 for T500mm seconds. Table 3 shows the results of the J-Ring test, revealing varying degrees of difference among different concrete mixes. The conventional mix exhibits the maximum difference, while Mix 2 and Mix 2PPF shows the least difference, with of 5mm and 7mm, respectively. Notably, Mix 1 and Mix 1PPF demonstrates an increase in J-Ring difference compared to other mixes. This observed decrease in difference may be attributed to the reduced viscosity resulting from the incorporation of mineral admixtures.

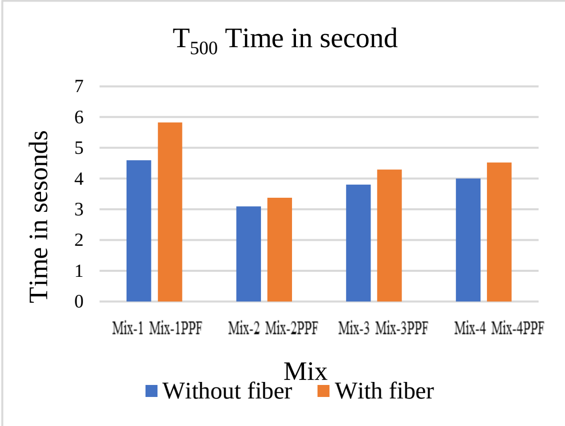

Fig 3. T500 Time in seconds for QBSCC

Table 4. Flow Properties of QBSCC

MIX	V funnel time in seconds	L-box ratio	U-box (h_2-h_1) in mm
MIX-1	11	0.84	18
MIX-2	6.8	0.93	8
MIX-3	7.6	0.9	12
MIX-4	9	0.87	14
MIX-1PPF	15.2	0.77	27
MIX-2PPF	7.89	0.91	11
MIX-3PPF	9.25	0.87	16
MIX-4PPF	11.24	0.83	19

4.1.2. V funnel test

Figure 4 illustrates the results of the V-funnel test. The values obtained for the quaternary blended SCC mix range from 6.8 to 11 seconds for mixes without fibers and 7.89 to 15.2 seconds for mixes with fibers, Mix 2, Mix 3 and Mix 2PPF fall under class VF1 and rest of the mix fall in the VF2 class according to EFNARC 2005 standards. These values comfortably meet the maximum acceptable limit of 25 seconds

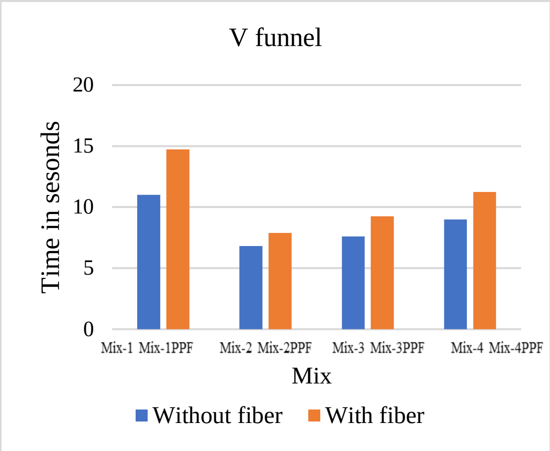

Fig 4. V funnel of QBSCC

4.1.3 U-Box

The U-box test, is aimed at assessing the passing ability of SCC. Flow and passing ability of the SCC mix are considered as good when this difference of filling heights is zero. Figure 5 showcases the variation in the difference in filling heights for all mixes. Mix 2, comprising (50% OPC+10% SF+ 30% FA+ 10% GGBS), demonstrates the minimum difference in filling height, both with and without fiber mix, suggesting the superior passing ability of SCC. This underscores the positive impact of mineral admixture utilization on enhancing the flow ability, passing ability, and filling ability of SCC

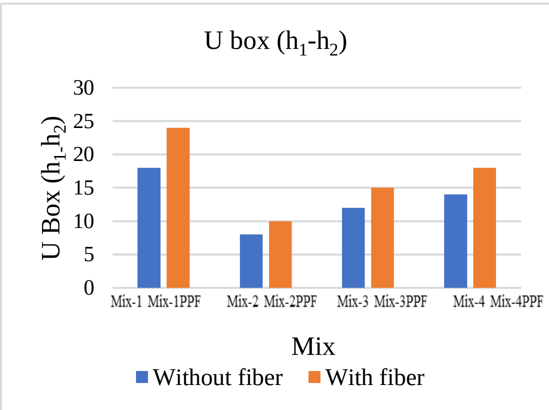

Fig 5. U- Box

4.1.4. L Box

The passing ability of concrete is measured by indicating the blocking ratio. Figure 6 shows the blocking ratio value of all quaternary blended SCC. The blocking ratio of all quaternary blended SCC mixes is in the range of 0.84 to 0.93 for without fiber and 0.77 to 0.91 for with fiber mix and it is well below the limitation suggested in EFNARC 2005. Cement replacement with mineral admixture can improve the passing ability of SCC and decrease the blockage of coarse aggregate to some extent.

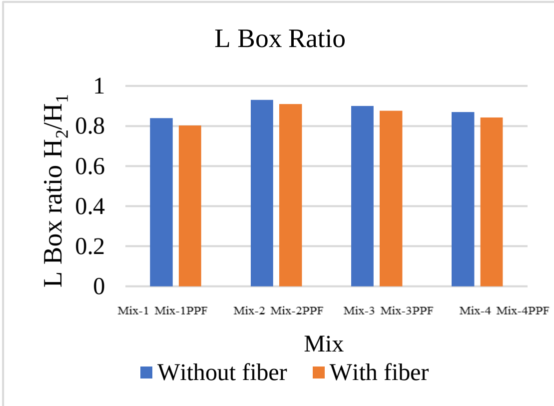

Fig 6. L Box

The observed variations in deformability and passing ability suggest that the incorporation of mineral admixtures enhances the rheological properties of concrete, offering an improvement over conventional concrete. Mix 2 outperforms the rest in terms of rheological properties, regardless of fiber. Notably, as the proportion of GGBS increases from Mix 2 to Mix 4, there is a gradual decline in slump flow, an increase in the flow time, and slight resistance in the passing ability of concrete, suggests a potential trade-off between flow ability. Mix 2's superior performance can be attributed to its higher content of fly ash. Fly ash, with fine particle size, is introduced into a concrete mix alongside cement, its particles act as microscopic spheres or ball bearings. These fine particles, being smaller than typical cement particles, fill the interstitial spaces between the larger cement grains. As a result, they create a lubricating layer that allows the cement particles to move more freely and slide past each other with reduced resistance. The reduction in friction facilitates better workability and flow without compromising the stability of the fresh

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concrete. The addition of Polypropylene fibers makes the mix more viscous thus slowing down the flow of concrete resulting in a decrease in the workability of concrete for mix with fiber as compared to mix without fiber.

4.2. STRENGTH PROPERTIES OF QUATERNARY BLENDED SELF-COMPACTING CONCRETE

In this study, the fundamental mechanical properties of self-compacting concrete (SCC) were investigated with a focus on compressive strength, split tensile strength, and flexural strength.

4.2.1. Compressive strength

The Compressive strengths of the Quaternary Blended Self-Compacting Concrete (QBSCC) mixes prepared with SCM and 0.2% polypropylene fibers are shown in Table 5 and Figure 7 Graphical representation of the Compressive strength as curing time increases from 7 to 56 days, there is a general trend of performance improvement across all mixes. However, the rate of performance improvement varies for each mix, suggesting differences in the kinetics of hydration and strength gain. Mix-4 and Mix 4 PPF consistently demonstrated the highest performance values across all time intervals compared to the other mixes.

Table 5. Compressive Strength of QBSCC

COMPRESSIVE STRENGTH			
MIX	7 Days	28 Days	56 Days
MIX-1	30.17	41.43	44.12
MIX-2	27.41	39.85	46.34
MIX-3	30.77	43.06	49.58
MIX-4	30.87	44.21	50.02
MIX-1 PPF	31.56	44.25	47.34
MIX-2 PPF	29.29	42.89	50.94
MIX-3 PPF	33.30	46.96	55.15
MIX-4 PPF	34.17	49.52	56.64

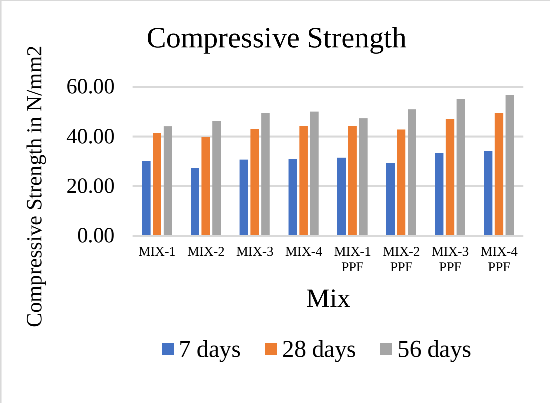

Fig 7. Compressive Strength of QBSCC

This superiority may be due to the higher content of GGBS and the incorporation of polypropylene fibers, which increases the compressive strength of the concrete. The cube compressive strength of specimen Mix 2 (50% OPC+10% SF+ 30% FA+ 10% GGBS), on days 7 and 28 was 9.15% and 3.82% lower, respectively, then that of specimen Mix 1. Mix 2 PPF (50% OPC+10% SF+ 30% FA+ 10% GGBS+ 0.2% PPF) is 7.19% and 3.07% lower than that of the Mix 1 PPF on the 7^{th} day, and 28^{th} day, respectively. Indicating that substantially replacing OPC with FA in SCC resulted in considerably lower cube compressive strength due to its slow pozzolanic reaction Compressive strength is increased by 5.06% and 7.60% compared to Mix-1 and mix 1 PPF on 56 days this could be attributed to the enhancement in the pozzolanic reaction of FA at the later ages. The cube compressive strength of all the specimens (50% SCM) was higher than that of the control specimens with and without fibers, indicating that replacing OPC with a combination of FA, GGBS, and SF resulted in an increase in the compressive strength. When comparing mix 3 and mix 4 with mix 1, there was a rise in compressive strength by 1.97%, 3.93%, and 12.38% for mix 3, and by 2.32%, 6.71%, and 13.37% for mix 4. This increase was observed over the periods of 7 days, 28 days, and 56 days, respectively. Similarly, when comparing mix 3PPF and mix 4PPF with mix 1PPF, there was a more significant increase in compressive strength. For mix 3PPF, the increase was 5.51%, 6.12%, and 16.5%, and for mix 4PPF, it was 8.27%, 11.91%, and 19.65%. This increase was also observed over the same periods of 7 days, 28 days, and 56 days, respectively. This is mainly attributed to the pozzolanic reaction and synergy between these SCMs with different particle sizes. It is evident from Fig. 1 that at a given SCM replacement level, replacing the cement by a combination of FA, GGBS and SF has consistently increased the compressive strength. For MIX-1, the addition of PPF resulted in an increase of 4.6%, 6.8%, and 7.3% in strength at 7, 28, and 56 days, respectively. For MIX-2 with PPF, an increase of 6.8%, 7.6%, and 9.8% were observed at the same intervals. For MIX-3 with PPF, an increase of 8.2%, 9%, and 11.23% was observed. Finally, MIX-4 with PPF showed an increase of 10.68%, 12%, and 13.24%, respectively. The addition of PP fibers did not significantly affect the compressive strength in all samples; however, the compressive strength was greater than that of the control sample. The enhancement in strength is due to the effect of aggregate and fiber interlocking mechanisms, which prevented and delayed the extensive generation of micro cracks and the ability to restrain the extension of cracks, reduce the stress concentration at the tip of cracks, change the direction of cracks, and delay the growth rate of cracks. According to the test results, Comparing the performance of quaternary SCC mixes with Mix 4 PPF (50% OPC+10% SF+10%FA + 30% GGBS + 0.2% PPF) with other mixes it emerges as the top-performing variant across all time intervals. According to the test results, the conclusion can be drawn that using a combination of FA, GGBS, and SF can increase the cube compressive strength of SCC mixes. This is mainly attributed to several reasons: firstly, several previous programs have concluded that GGBS has hydraulic activity with cement in addition to certain pozzolanic activity. Secondly, SF with a high reactivity can react with calcium hydroxide (Ca (OH) 2) to form calcium silicate hydrate (C-S-H) and densified silica fume with a fine particle can fill the surface pores of concrete and pack the pores in a cement matrix and fill the interfacial transition zone, effectively, thus enhancing the compactness of the structure and increasing the compressive strength of SCC mixes. Finally, the remarkable synergistic effect between FA, GGBS, and SF leads to a higher packing density and denser microstructure, thus contributing to an increase in the compressive strength of SCC.

4.2.2. Split Tensile Strength

The tensile strength of various concrete mixtures was assessed using cylindrical specimens subjected to testing at 7 days, 28 days, and 56 days of curing. The split tensile strength values for all the self-compacting concrete mixes obtained are presented in the Table 6.

Table 6. Split Tensile Strength of QBSCC

SPLIT TENSILE STRENGTH			
MIX	7 Days	28 Days	56 Days
MIX-1	2.37	3.08	3.35
MIX-2	2.07	2.95	3.40
MIX-3	2.43	3.12	3.71
MIX-4	2.62	3.35	4.00
MIX-1 PPF	2.55	3.38	3.62
MIX-2 PPF	2.31	3.32	3.90
MIX-3 PPF	2.75	3.67	4.30
MIX-4 PPF	3.02	4.01	4.81

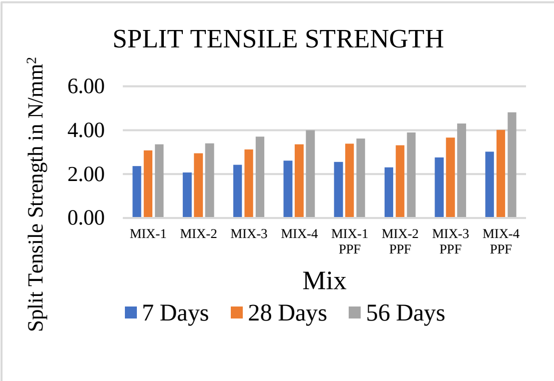

Fig 8. Split tensile Strength of QBSCC

The split tensile strengths of the QBSCC mixes prepared with SCM and 0.2% polypropylene fibers after 7, 28, and 56 days are shown in Table 6 and Figure 8 Graphical representation of the split tensile strength the split tensile strength values of the QBSCC mixes prepared with SCM ranged from 2.07 to 2.62 MPa at 7 days, 2.95– 3.35 MPa at 28 days, and 3.4–4.00 MPa at 56 days. Similar to the compressive strength, the split tensile strength decreased with increasing FA replacement due to the low reactivity of FA. The percentage decrease in split tensile strength at 7 and 28 days was found to be 12.67% and 4.38%, respectively, for specimens without PPF and 9.41% and 1.78%, respectively, for specimens with PPF for 30% FA replacement (mix 2). On 56 days of curing, a percentage increase of 1.53% was observed in the absence of PPF and 7.73% in the presence of PPF mix. It was clear that the rate of strength gain increased with an increase in curing age. A similar behaviour was also observed: the early-age compressive strength of FA replaced concrete mix was less than that of the conventional mix, but the rate of strength increased with increasing curing age. The split tensile strength was higher than that of the conventional specimen for the replacement of (50% OPC+10% SF+ 20% FA+ 20% GGBS) mix 3 and (50% OPC+10% SF+ 10% FA+ 30% GGBS) mix 4 This is due to the high reactivity and high surface area of SCM, which enhance the strength by forming C-S-H gel. The split tensile strength increased at 7 days (2.57%, 10.51%), 28 days (1.17%, 8.76%), and 56 days (10.58%, 19.36%), for mix 3 and mix 4, respectively. When Mix 1 PPF was compared with Mix 3PPF and Mix 4 PPF, the percentage increases in split tensile strength were 7.96% and 18.43% for 7 days, 8.58% and 18.64% for 28 days, and 18.78% and 32.87% for 56 days of curing, respectively. Conversely, QBSCC mixed with SCM and 0.2% polypropylene fibers exhibited split tensile strength values ranging from 2.31 to 3.02 MPa at 7 days, 3.90–4.81 MPa at 28 days, and 3.90–4.81 MPa at 56 days. The split a conventional mix with PPF and without PPF, the split tensile strength values are observed. The increase ranges from 7.59% to 15.3% at 7 days, 9.6% to 19.56% at 28 days, and 8% to 20.23% at 56 days for all SCC mixed with PPF. This enhancement in strength is attributed to the addition of polypropylene fiber, which resisted the opening and expansion of early and micro cracks and prevented the continuity of crack formation and propagation due to the fibers bridging effects in the samples. The enhancement of compressive strength is also reflected in the split tensile strength of the SCC mixes. The addition of supplementary cementitious materials (SCM) has varying effects on the split tensile strength of Quaternary Blended Self-Consolidating Concrete (QBSCC) mixes compared to the reference mix 1 and mix 1PPF mix. QBSCC mix 4 with and without PPF show better split tensile strength properties compared to other QBSCC mixes. The addition of SCM to the QBSCC mixture increases the split tensile strength compared with that of conventional mixtures. SCM improves packing and fills voids, resulting in denser concrete. In addition, the late pozzolanic reaction of SCM contributes to an increase in the split tensile strength at later ages.

4.2.3 Flexural strength

The flexural strength values for all the self-compacting concrete mixes obtained are presented in the Table 7, The flexural strength results for the SCC mix at 7, 28 and 56 days are presented in Table 7 and Figure 9 shows the graphical representation of Flexural strength. QBSCC mixes prepared with SCM exhibit flexural strength values ranging from 4.19 MPa to 4.86 MPa at 7 days 6.02 MPa to 6.15 MPa at 28 days and 6.19 MPa to 6.73 MPa at 56 days. Conversely, mixes prepared with SCM and 0.2% PPF demonstrate flexural strength values ranging from 4.47 MPa to 5.53 MPa at 7 days, 6.60 MPa to 7.20 MPa at 28 days and 6.73 MPa–7.90 MPa at 56 days. The flexural strength was higher than that of the conventional specimen (mix 1) for the replacement of mix 3 (50% OPC+10% SF+20% FA + 20% GGBS) and mix 4 (50% OPC+10% SF+10% FA + 30% GGBS). The flexural strength increased at 7 days (12.77%, 16%), and 56 days (4.85%, 8.87%) for mix 3 and mix 4, respectively. Fig. 9. Flexural Strength of QBSCC When Mix 1 PPF was compared with Mix 3PPF and Mix 4 PPF, the percentage increases in flexural strength were 18.66%, 23.88% for 7 days, 6.06%, 9.09% for 28 days, and 6.93% and 17.33% for 56 days of curing, respectively.

Table 7. Flexural Strength of QBSCC

FLEXURAL STRENGTH			
MIX	7 Days	28 Days	56 Days
MIX-1	4.19	6.02	6.19
MIX-2	3.93	5.75	6.21
MIX-3	4.73	6.10	6.49
MIX-4	4.86	6.15	6.73
MIX-1 PPF	4.47	6.60	6.73
MIX-2 PPF	4.33	6.40	6.99

MIX-3 PPF	5.30	7.00	7.20
MIX-4 PPF	5.53	7.20	7.90

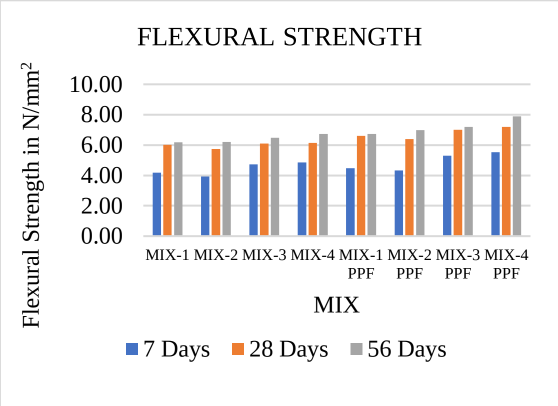

Fig 9. Flexural Strength of QBSCC

When Mix 1 PPF was compared with Mix 3PPF and Mix 4 PPF, the percentage increases in flexural strength were 18.66%, 23.88% for 7 days, 6.06%, 9.09% for 28 days, and 6.93% and 17.33% for 56 days of curing, respectively. The flexural strength values for MIX-1 increased by 6.59%, 9.63%, and 8.78% at 7, 28, and 56 days, respectively, on comparing without PPF mix with the PPF incorporated mix. For MIX-2, an increase of 10.26%, 11.38%, and 12.56% were observed at the same intervals. For MIX-3 containing PPF, an increase of 12.15%, 14.75%, and 10.94% was observed. Finally, MIX 4 with PPF showed an increase of 13.83%, 17.16%, and 17.31%, respectively. The increase in flexural strength is due to the addition of Supplementary Cementitious Materials (SCM) has diverse effects on the flexural strength of Quaternary Blended Self-Compacting Concrete (QBSCC) mixes compared to the reference mix incorporation of fiber also facilitated in achieving the flexural strength due to the bridging effect of fiber as a result of a satisfactory mechanical bond among the fibers and concrete. In other words, when a flexural load is applied to the fiber reinforced concrete, the fiber present in the concrete is acted as a secondary reinforcement to bridge the crack by providing resistance to the crack propagation at the failure plane. Mix 4 PPF exhibits the highest flexural strength, while mix 1 shows the lowest. The flexural strength is often higher than split tensile strength in concrete is due to the nature of the stresses involved. In a flexural strength test, the highest stress occurs at the outermost fibers of the beam, which are furthest from the neutral axis, while the material within the neutral axis experiences lower levels of stress. This allows the material to carry a higher load and thus exhibit a higher flexural strength.

4.3. DURABILITY: ACID ATTACK TEST

Cubes, Cylinders, and Prisms from SCC specimens were used in the test. The sulfuric resistance of the mixes was assessed using 15% strength sulfuric acid. At first, the specimens were water-cured for 7 and 28 days. The percentage weight loss for the four mixes without fiber and with polypropylene fiber SCC specimens, respectively, following a 28-day acid attack exposure period in a 15% H2SO4 solution is given in Tables 8 and 9. This kind of attack serves as an expedited testing method to show how well concrete mixes withstand acid attack. There are no standards in the ASTM which is entirely dedicated to evaluate the resistance of concrete mixtures to the invasion of sulfuric acid, thus ASTM C267, which is the standard test method for the chemical resistance of motors, grouts, and polymer concrete, was used as the basis for this test procedure.

Fig 10. Specimen curing in acid and after exposure to H2SO4 solution

Table 8. Change in weight after 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

Type of mix	7 days water cured % loss in weight after 28 days immersion in H_2SO_4 media		
	Cubes	Cylinders	Prisms
MIX-1	2.86	2.93	2.91
MIX-2	1.68	2.06	1.92
MIX-3	1.03	1.15	1.22
MIX-4	0.78	0.73	0.86
MIX-1 PPF	2.82	2.91	2.6
MIX-2 PPF	1.61	2.06	1.82
MIX-3 PPF	0.97	1.12	1.09
MIX-4 PPF	0.77	0.68	0.83

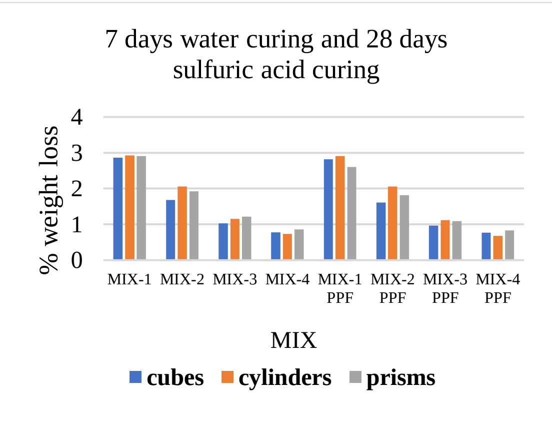

Fig 11. Change in weight after 7 days water curing and 28 days of sulfuric acid curing for with and without fiber mixes.

Table 9. Change in weight after 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

Type of mix	28 days water cured % loss in weight after 28 days immersion in H_2SO_4 media		
	Cubes	Cylinders	Prisms
MIX-1	1.79	1.88	1.86
MIX-2	0.85	0.91	0.95
MIX-3	0.42	0.56	0.59
MIX-4	0.34	0.38	0.41
MIX-1 PPF	1.75	1.82	1.8
MIX-2 PPF	0.81	0.84	0.88
MIX-3 PPF	0.39	0.5	0.49
MIX-4 PPF	0.32	0.35	0.36

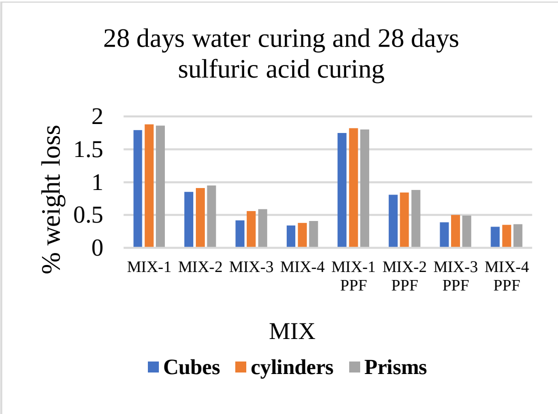

Fig 12. Change in weight after 28 days water curing and 28 days of sulfuric acid curing for with and without fiber mixes.

The table 8 and table 9 data illustrates the change in weight after 28 days of immersion in a sulfuric acid solution for Self-Compacting Concrete (SCC) mixes, both with and without fiber addition.

Table 10. Loss of Compressive strength after 7 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

Type of mix	Compressive strength after 28 days water curing	Compressive strength after 28 days immersion in H_2SO_4 media	% Loss in Compressive strength after 28 days immersion in H_2SO_4 media
	Cubes	Cubes	cubes
MIX -1	41.43	34.0	17.94
MIX -2	39.85	34.56	13.28
MIX -3	43.06	38.64	10.50
MIX -4	44.21	40.27	8.92
MIX -1 PPF	44.25	36.62	17.24
MIX -2 PPF	42.89	36.95	13.85
MIX -3 PPF	46.96	41.94	10.7
MIX -4 PPF	49.52	45.09	8.94

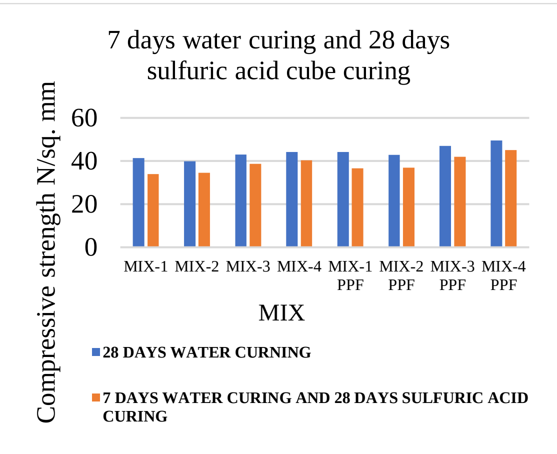

Fig 13. Loss of Compressive strength after 7 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

The impact of immersion in a sulfuric acid solution on the compressive strength of self-compacting concrete (SCC) mixes with and without fiber addition is demonstrated by the data shown in Tables 10, respectively, these findings imply that fiber addition to SCC mixes may be able to somewhat lessen the negative effects of sulfuric exposure. Comparing MIX-3 PPF and MIX-4 PPF to mixes without fiber inclusion, neither of these two shows better resistance to sulfuric acid attack. When compared to all other mixes, the MIX-4PPF exhibits the lowest reduction in strength loss (with fiber and without fiber).

Table 11. Loss of split tensile strength after 7 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

Type of mix	Split tensile strength after 28 days water curing	Split tensile strength after 28 days immersion in H_2SO_4 media	% Loss in Split tensile strength after 28 days immersion in H_2SO_4 media
	Cylinder	Cylinder	Cylinder
MIX-1	3.08	2.50	18.94
MIX-2	2.95	2.52	14.54
MIX-3	3.12	2.73	12.50
MIX-4	3.35	3.01	10.25
MIX-1 PPF	3.38	2.75	18.63
MIX-2 PPF	3.32	2.78	16.26
MIX-3 PPF	3.67	3.21	12.54
MIX-4 PPF	4.01	3.58	10.72

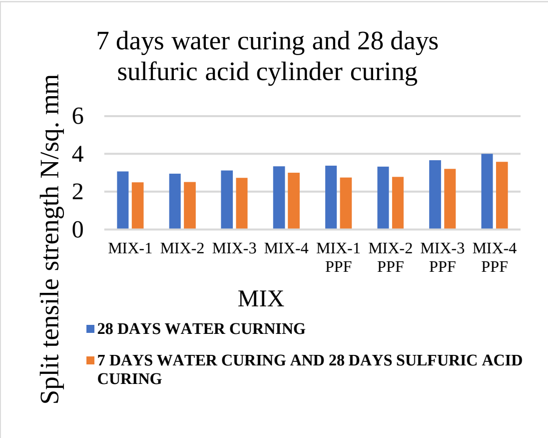

Fig 14. Loss of split tensile strength after 7 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

The effects of immersion in a sulfuric acid solution on the split tensile strength of self-compacting concrete (SCC) mixes with and without fiber addition are shown in Table 11 respectively.

These findings imply that incorporating fibers to SCC mixes may help reduce the negative consequences of exposure to sulfuric acid. Comparing MIX-3PPF and MIX-4PPF to all other mixes, both with and without fiber addition, demonstrates improved resistance to sulfuric acid attack. Notably, MIX-4PPF performs better than all other mixes in reducing the effects of sulfuric acid assault, as seen by the lowest decline in strength loss across all mixes, both with and without fiber addition.

Table 12. Loss of flexural strength after 7 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

Type of mix	Flexural strength after 28 days water curing	Flexural strength after 28 days immersion in H_2SO_4 media	% Loss in Flexural strength after 28 days immersion in H_2SO_4 media
	Prism	Prism	Prism
MIX-1	6.02	5.01	16.78
MIX-2	5.75	4.93	14.26
MIX-3	6.1	5.35	12.30
MIX-4	6.15	5.49	10.73
MIX-1 PPF	6.60	5.40	18.18
MIX-2 PPF	6.40	5.39	15.78
MIX-3 PPF	7.00	6.19	11.58
MIX-4 PPF	7.20	6.40	11.12

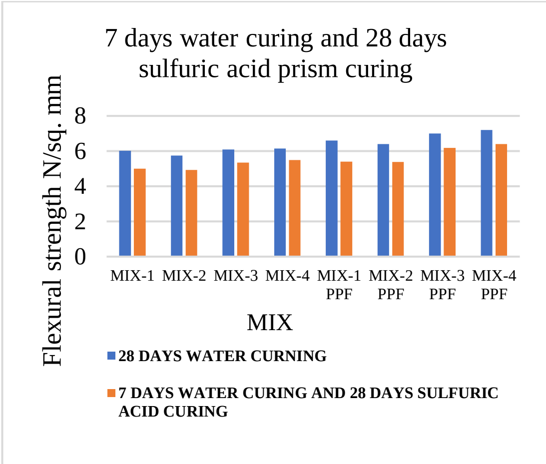

Fig 15. Loss of flexural strength after 7 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

The results depicted in Table 12 outline the impact of immersion in a sulfuric acid solution on the flexural strength of self-compacting concrete (SCC) mixes with and without fiber addition, respectively According to these findings, adding fibers to SCC blends may help lessen the detrimental impact of sulfuric exposure on flexural strength. Out of all the mixes, MIX-4PPF shows the least amount of flexural strength drop, demonstrating its greater ability to withstand the destructive effects of sulfuric acid attack.

Table 13. Loss of Compressive strength after 28 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

Type of mix	Compressive strength after 56 days water curing	Compressive strength after 28 days immersion in H_2SO_4 media	% Loss in Compressive strength after 28 days immersion in H_2SO_4 media
	Cubes	Cubes	Cubes
MIX -1	44.12	39.74	9.92
MIX -2	46.34	42.71	7.84
MIX -3	49.58	46.23	6.76
MIX -4	50.02	47.75	4.53
MIX -1 PPF	47.34	42.34	9.67
MIX -2 PPF	50.94	47.68	6.39
MIX -3 PPF	55.15	52.04	5.63
MIX -4 PPF	56.64	54.07	4.53

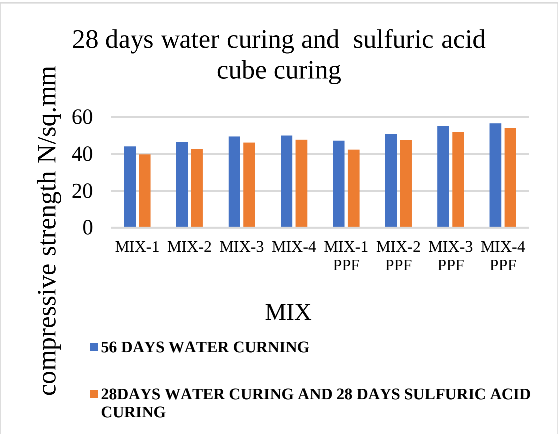

Fig 16. Loss of Compressive strength after 28 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

The data shown in Tables 13 demonstrates how immersion in a sulfuric acid solution affects the compressive strength of mixes of self-compacting concrete (SCC) after 28 days, with and without the addition of fiber,

These results suggest that the addition of fibers to SCC mixes contributes to better resistance against the detrimental effects of sulfuric acid exposure on compressive strength, this data highlight how different SCC mixtures react when fiber is added and immersed in a sulfuric acid solution. When polypropylene fiber was added, the compressive strength of the majority of mixes decreased very little, although MIX-4 PPF showed a minor improvement over the others without losing strength

Table 14. Loss of Split tensile strength after 28 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

Type of mix	Split tensile strength after 56 days water curing	Split tensile strength after 28 days immersion in H_2SO_4 media	% Loss in Split tensile strength after 28 days immersion in H_2SO_4 media
	Cylinder	Cylinder	Cylinder
MIX-1	3.35	2.98	11.09
MIX-2	3.4	3.17	6.85
MIX-3	3.71	3.48	6.11
MIX-4	4	3.74	6.51
MIX-1 PPF	3.62	3.27	9.66
MIX-2 PPF	3.9	3.59	7.94
MIX-3 PPF	4.3	4.02	6.51
MIX-4 PPF	4.81	4.56	5.19

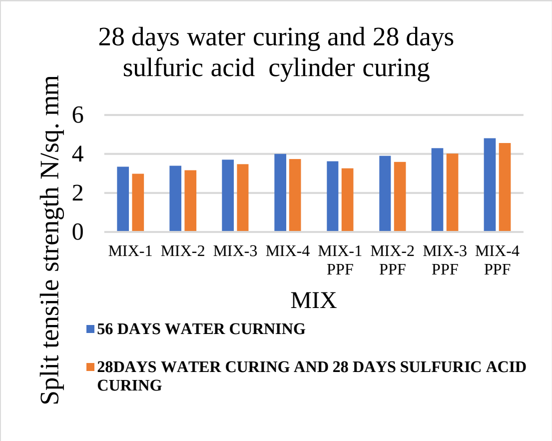

Fig 17. Loss of Split tensile strength after 28 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

The data presented in Table 14 demonstrate the impact of immersion in a sulfuric acid solution on the split tensile strength of self-compacting concrete (SCC) mixes, with and without fiber addition, when polypropylene fibers (PPF) were added to self-compacting concrete (SCC) mixes, the percentage loss of split tensile strength following immersion in a sulfuric acid solution was reduced. This was particularly noticeable when compared to mixes from MIX-1, MIX-2, MIX-3, and MIX-4.

Table 15. Loss of Flexural strength after 28 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

Type of mix	Flexural strength after 56 days water curing	Flexural strength after 28 days immersion in H_2SO_4 media	% Loss in Flexural strength after 28 days immersion in H_2SO_4 media
	Prism	Prism	Prism
MIX-1	6.19	5.40	12.76
MIX-2	6.21	5.59	9.98
MIX-3	6.49	6.03	7.08
MIX-4	6.73	6.31	6.24
MIX-1 PPF	6.73	5.98	11.44
MIX-2 PPF	6.99	6.28	10.15
MIX-3 PPF	7.2	6.60	8.33
MIX-4 PPF	7.9	7.08	10.37

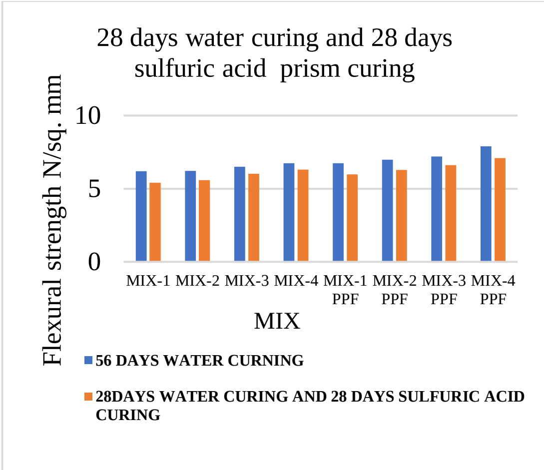

Fig 18. Loss of Flexural strength after 28 days of water curing and 28 days of immersion in a sulfuric acid solution for SCC mixes with and without fiber addition.

The information in Tables 15 shows how immersion in a sulfuric acid solution affects the flexural strength of mixes of self-compacting concrete (SCC) after 28 days, both with and without the addition of fiber, Flexural strength was significantly increased by adding polypropylene fibers (PPF) to the SCC mixes as compared to mixes without fibers; the benefits varied depending on the mix. When compared to all other mixes, MIX-4PPF performs better (with and without fiber addition).

CONCLUSION

1. When compared to a mix containing 100% cement, the flow properties of the mixture improved with the substitution of additional cementitious materials. However, the rheological qualities of the mix were further diminished by the addition of polypropylene fiber.
2. While Mix-2 has a higher fly ash component than the other mixes, it performs superior in terms of rheological qualities regardless of the fiber. The lubricating layer that is created by fine particle sizes acts as tiny spheres or ball bearings, enabling the cement particles to move more freely and slide past one another with a lower coefficient of resistance.
3. Effectively manufacturing self-compacting concrete (SCC) is feasible by substituting various mineral admixtures such as fly ash, GGBS, and silica fumes for cement. Improved outcomes result from the complementary effects of these mineral admixtures.
4. The experimental results indicate that the mix with a high fly ash content initially exhibited a sluggish pozzolanic reaction, resulting in low strength, which gradually increased over time. This phenomenon can be attributed to the enhanced pozzolanic reaction of fly ash at later ages, while the presence of silica fume affects strength at earlier ages.
5. The insertion of fibers further enhanced the mechanical properties of the concrete. The fibers in the samples exerted a bridging effect, which contributed to the increase in strength.
6. After 56 days, it was observed that the strength of the QBSCC mixes surpassed that of the control mixes. This strength enhancement can be attributed to the increased pozzolanic response and additive effect of the various admixtures utilized.

In comparison to the other mixes, both Mix-4 and 7.Mix-4PPF, with and without polypropylene fiber, exhibited the highest strength, whereas Mix-1 displayed the lowest strength.

8. The weight loss analysis of concrete specimens, including cubes, cylinders, and prisms, containing various proportions of silica fume, GGBFS, and fly ash, has revealed enhanced resistance to sulfuric acid intrusion compared to the reference mix.
9. Compared to both with and without fiber for 7 and 28 days of water curing, when subjected to 28 days of sulfuric acid invasion, the weight loss for specimens cured for 7 days shows a higher weight loss than those cured for 28 days and subsequently exposed to sulfuric acid invasion for 28 days.
10.The specimens (cubes, cylinders, prisms) that which are moisture cured for both 7 and 28day water curing and were subsequently subjected to 28 days of sulfuric acid invasion exhibited a higher percentage weight loss.
11. Notably, the blend incorporating Mix-4 and Mix-4PPF demonstrated superior resistance in both 7 and 28day water cured specimens, even after exposure to 28 days of sulfuric acid invasion.
12.Concrete specimens (cubes, cylinders, prisms) that which are moisture cured for 7-day and were then subjected to 28 days of acid attack exhibited a decrease in strength across all aspects, including compressive strength, split tensile strength, and flexural strength, compared to their 28-day strength counterparts.
13. The concrete specimens which are moisture cured for 28 days and followed by 28 days of acid attack, exhibited reduced strength in all parameters - compressive strength, split tensile strength, and flexural strength, compared to specimens cured for 56 days.
14. Based on the results, it can be concluded that concrete specimens (cubes, cylinders, prisms) subjected to 7 days of moisture curing followed by 28 days of acid attack exhibit a marginally higher loss in strength, when cement is partially replaced by mineral admixtures.
15.For instance, the blend incorporating (10% fly ash, 30% GGBFS, and 10% silica fume) Mix-4 and Mix-4PPF demonstrated increased resistance when specimens were water cured for 28 days and subsequently subjected to 28 days of sulfuric acid invasion.
16.By preventing crack formation and reducing porosity, polypropylene fibers enhance the microstructure of concrete and help to make the concrete more resistant to sulfuric acid attack.

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