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Effect of Polypropylene Fibres on Strength and Durability Performance of M-35 Self Compacting Concrete

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ABSTRACT

The durability of the self compacting concrete is one of the prominent areas of concern in recent years since it has become prevalent due to its ease ofhandling in the construction industries. However, there is a lack of detailed dur-ability study of M-sand self compacting concrete with polypropylene fibres in theliterature. In this paper, self compacting concrete made by Portland pozzolana cement with natural sand and M-sand, different percentages of volume fraction (0%, 0.1%, 0.15% and 0.2%) polypropylene fibres with M-sand is thoroughly inves- tigated for fresh properties, hardened properties, drying shrinkage, water absorp- tion, permeability, acid resistance and corrosion crack initiation tim Further, SEManalysis was carried out to know the effect of polypropylene fibre on the concrete microstructure. The results confirmed that the use of M-sand has improved the fresh, hardened and durability properties of the self compacted concrete than natural sand. Also, it is observed that the addition of polypropylene fibres has reduced the fresh properties of self compacted concrete. However, M-sand with 0.15% polypropylene fibres has slightly improved the strength of self compactingconcrete, compression strength by 6.97%, split tensile by 8.68% and flexure Further, it has reduced the drying shrinkage by 40%, water absorp- tion by 30%, water penetration by 33.33%, and increased the chemical resistance, surface crack initiation period than the natural sand self compacting concrete. Finally, this study concludes that M-sand with 0.15% polypropylene fibres improves the durability of self compacting concrete by reducing effect from aggressive environments and in turn contributes to increased corrosion resistance of reinforce-ments embedded in concrete. Thus, the study supports the use of self compacting concrete with M-sand and optimum amount of polypropylene fibres to achieve required sustainability in terms of strength and durability.

Subjects: Concrete & Cement; Structural Engineering; Waste & Recycling

Keywords: compression strength; durability; flexural strength; polypropylene fibre; selfcompacting concrete

INTRODUCTION

Self compacting concrete (SCC) use in the construction industry is forefront these days due to itsproperties and ease of handling (Prakash, Raman, et al., 2021). The use of SCC can save the costsand manpower requirements for the work. It has gained popularity due to its advantages in recentdays. SCC was first developed in Japan. Later, a detailed study on the SCC properties was conducted by Okamura and Ozawa (Okamura & Ozawa, 1996; Ouchi et al., 1996). SCC consists ofa high amount of powder content compared to normal concrete, which helps the concrete to flowin its fresh state, increasing the cohesiveness and inter particle link. Also, it maintains uniformity while moulding the concrete and can pass through congested reinforcements. The key focuses ofthe new SCC standards are the capacity for filling, the capacity for passing, and the resistance to segregation. SCC ability is measured by a series of tests using distinguished apparatus in the freshstate while finalising the mix design by following the guidelines in EFNARC 2005 (EFNARC, 2005).

Concrete durability deficiency increases the possibilities of steel corrosion in concrete due to thepenetration of external agents such as chloride and sulphate (Rossi et al., 2020). The carbon dioxide, chloride and sulphate ions penetration alter the concrete's pH value and increases the corrosion possibilities. The corrosion process develops expansive pressure, which leads to the microcracks formation on concrete around the steel bar (Šavija et al., 2015). This crack growth increases with time, reaches the surface and deteriorates by breaking the concrete and steel bond(L. Wang et al., 2017). Corrosion of the embedded steel has become the major cause of failures due to the deterioration of concrete in reinforced structures and prestressed structures exposed to

MATERIALS AND METHODOLOGY

The Portland Pozzolana Cement (PPC), two types of fine aggregates, coarse aggregate, polypropylene fibres (PPF), potable water and superplasticiser are used in the concrete mix. The PPC cement with 32% fly ash content confirming to IS 1489 (BIS:1489Part 1, 1991) with specific gravity of 2.92 and havinga fineness of 4% (i.e. % weight retained on a 90 µm IS sieve) is used as a binder in SCC. The initial andfinal setting time of PPC after testing was found to be 41 minutes and 366 minutes, respectively.

The angular aggregate of crushed granite stone of size 4.75 to 12.5 mm is used as coarse aggregate. The size distribution of considered coarse aggregate from the sieve analysis in termsof percenage passing are 96.8, 67.09 and 5.45 for sieve sizes of 12.5 mm, 10 mm and 4.75 respectively.

Table 1. The abbreviations used in the paper

Abbreviation	Description
EFNARC	European Federation of National AssociationsRepresenting for Concrete
M-sand	Manufactured Sand
PPF	Polypropylene Fibre
PPC	Portland Pozzolana Cement
SCC	Self Compacting Concrete
SEM	Scanning Electron Microscopy
SCC_N	SCC mix with Natural sand
SCC_M	SCC mix with M-sand and No PPF
SCC_M_0.1F	SCC mix with M-sand and .1% PPF
SCC_M_0.15F	SCC mix with M-sand and .15% PPF
SCC_M_0.2F	SCC mix with M-sand and .2% PPF
UTM	Universal Testing Machine

Table 2. The properties of aggregates considered in the study

Properties	Coarse Aggregate	Natural Sand	M-Sand
Specific Gravity	2.66	2.626	2.73
Fineness Modulus	6.3	2.56	2.6
Water Absorption	0.6%	0.8%	1.1%
Moisture Content	0.3%	2.35%	1%

River sand and crushed granite stone sand, that is, M-sand are used as fine aggre- gates in the study. The fine aggregate and coarse aggregates considered are free from all deleterious materials. The properties of the aggregate considered are tabulated in Table 2. Thegrain size distribution of the fine aggregates considered is shown in Figure 1. Aggregates are tested as per IS 383–1970 (IS:383, 1970).

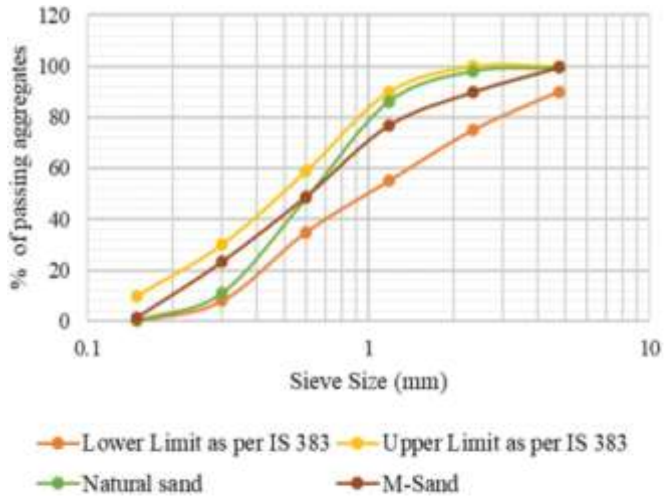


Figure 1. Sieve Analysis Resultsof Fine Aggregates.

To reduce the water content, polycarboxylate ether based superplasticiser is used as the high range water reducing agent. The admixture selected in this study acted as a water reducing agentand viscosity modifying agent, since it has both properties. As per the specification, the specific gravity of the considered admixture is 1.09. After many trials, the dosage selected for the presentstudy is 0.7% of the binding material content. With this, the PPF used in this work has a diameter of 24 microns, length of 12 mm and a specific gravity of 0.9. Figure 2 shows the polypropylene fibre, and the properties of PPF are listed in Table 3. As mentioned in IS 456: 2000 (IS 456, 2000), potablewater was used in this study.

The mix design for SCC is obtained by following EFNARC guidelines (EFNARC, 2005). Many trialswere conducted to obtain the optimum mix design, checking for its fresh properties. Once it satisfied the requirements, the casting of the mix was done and tested for strength after curing. Once targeted strength was achieved, the mix was finalised and all the required specimens for thestudy was cast.

Proper mixing and curing are fundamental aspects of getting good quality SCC. Since SCC hasmore paste content, it requires intensive and thorough mixing. The mixes were prepared using pan mixer as studies suggest this gives a good mix of SCC (Hemalatha et al., 2015). Initially dry mix of cement, sand and coarse aggregate was done to get an adequate mix. The water was added in three steps to get good workability. With an optimum dosage of admixture, 50% of the water wasmixed and kept. Initially 30% of water was added gradually to the dry mix and mixed thoroughly, later the water with admixture was added slowly and mixed for the next 2 minutes. The remaining 20% water is added gradually, looking at the consistency of the mix. After many trials, this particular method of adding water and admixture was found to give satisfying results for the used admixture in the study. Immediately fresh properties of concrete were checked with the part

Figure 2. Image of the polypro-pylene fibres.

Table 3. The properties of polypropylene fibres are considered in the study	
Properties	**Values**
Shape	Triangular
Diameter	24 microns
Specific Gravity	0.9
Melting point	160–165ºC
Tensile Strength	320–490 MPa
Elongation	60–90%
Young's Modulus	>4000 MPa
Alkaline Stability	Very good

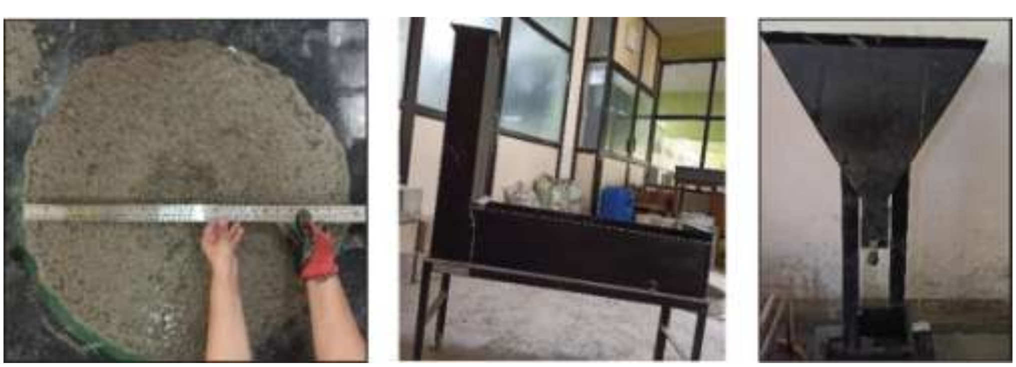
Table 4. The details of reference mix are considered in the study	
Mix contents	**Mix details**
PPC content (kg/m^3)	650
Coarse Aggregate (kg/m^3)	738.09
Fine Aggregate (kg/m^3)	741
Water (kg/m^3)	201.5
Admixture dosage (%)	0.7
Polypropylene Fibres (%)	0

Fresh Properties

Immediately after mixing, the fresh properties of the SCC were studied by conducting slump flow, T500, L box, V funnel tests to know the flowability, filling and passing ability, respectively. All the experiment to study fresh properties were conducted as per EFNARC (2005) guidelines (EFNARC,2005), the test images are shown in Figure 3.

Harden properties and durability tests

The hardened properties of SCC mixes were studied as per IS 516–1999 (IS 516, 1999), six speci-mens are considered for each test from every mix. The average values of the results are repre- sented in terms of graph and tabulation. Compression strength was obtained at 7 and 28 days as per IS 516–1999 (IS 516, 1999) on cubes of size 100 mm. A load of 2.5 kN/s was applied gradually, and the ultimate load was noted. The modulus of elasticity of the concrete was obtained at the age of 28 days. The load was gradually applied to the cylindrical specimen using universal testing machine (UTM) of capacity 1200kN, and the corresponding change in length was noted using dial gauges fixed along the cylinder length. Following the procedure mentioned in IS 516 the modulusof elasticity was calculated. All specimens were tested in saturated surface dry conditions. The



a) **Slump flow test** **b) L-box test** **c) V-Funnel test**

Figure 3. Tests conducted to determine the fresh propertiesof concrete.

Corrosion monitoring by AC impressed current method

The accelerated corrosion method has been used since then to study the corrosion of rebar in concrete. To monitor the corrosion crack initiation time, 150 mm cubes were cast by keeping the steel bar at the center, leaving a 30 mm cover from the bottom of the cube. After 28 days of curing period, accelerated corrosion test was conducted adopting the impressed current technique. Thespecimen was kept in a 5% NaCl solution such that only 3/4th of the concrete should be dipped in the solution. Then connected to DC power supply keeping embedded steel bar of 12 mm diameter as anode and copper rod as cathode, 0.04 Amp current was passed constantly and maintained throughout the test.

Figure 4. Permeability test onconcrete cube

Sample after 28 days curing

Accelerated corrosion set up

After one week accelerated corrosion

Figure 5. Accelerated corrosiontest

The current was applied till the appearance of a crack on the surface of thecube. The time taken for crack initiation was noted. The time taken for the appearance of the firstcrack was considered as a measure of the specimen's relative resistance against corrosion of reinforcement and chloride permeability. Figure 5 represents the accelerated corrosion test setup.

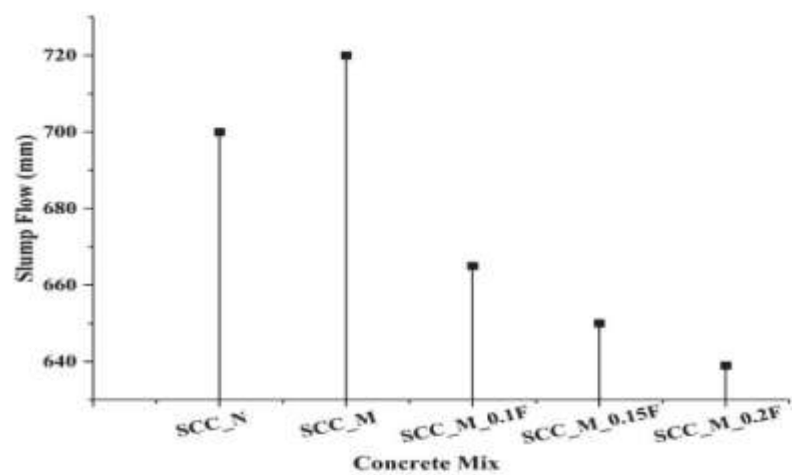
SEM study was conducted to observe the microstructure and to understand the interface zone between the PPF, cement paste and aggregate. The concrete specimen was taken for SEM (scan-ning electron microscopy) test after 90 days of curing, the sample of size 6 × 6 × 3 mm wascollected. The specimen with aggregates and fibres are used for study with proper care. Collected specimen is cleaned and dried at a temperature of 60–70ºC, golden coating was doneby using a vacuum coating machine.

RESULTS AND DISCUSSION

SCC has a very dense microstructure since it has more powder content and less coarse aggregate. The compression strength of the SCC depends on the workability of the concrete. The low work-ability of the concrete increases the porosity in the concrete. Figure 6a shows the slump flow testresults. The concrete mix SCC_M showed 2.9% more slump flow diameter than SCC_N. As the fibre content increases, SCC_M_0.1F showed 7.63%, SCC_M_0.15F showed 9.72% and SCC_M_0.2F showed an 11.25% reduction in the slump flow diameter. So, the result confirmed that concretemade of M-sand has a high flowing ability when compared with natural sand concrete for the same w/c ratio. And also, as the fibre content increased the slump flow was found to be reduced. L-box results, that is, H2/H1 values proved the inverse proportion with the fibres content. Very small variation between SCC_M and SCC_N was observed. And as the fibre content increased, H2/ H1 values were found to be decreased. The L-box test results are shown in Figure 6(b).

The T500 and V-Funnel test results are presented in Figure 7(a). It is observed that less time istaken by the concrete mix SCC_M compared to the SCC_N. The time taken in T-500 and V-Funnel tests is found to be inversely proportional to the percentage of polypropylene fibres. Less time represents greater flowability of the SCC. These results proved that M-sand improves the fresh properties of the SCC since it contains less silt content, proper gradation and also high specific gravity than natural sand. Also, the particle shape of the M-sand influences to get good flowabilityof SCC and to have improved fresh properties. But the use of fibres in SCC increases the surfacearea. The pastes in the concrete adhere to the fibres along with the aggregates, and internal friction increases between the aggregates and fibres as the paste is utilised to coat the fibre andaggregates. As the fibre content increased, the concrete becomes more viscous than the plain SCC and slump flow gets reduced. Similarly, with the flowing ability reduction in the other fresh properties of SCC.

Figure 7(b) represents the linear regression results of the V-funnel and T500 test of M-sand self compacted concrete. The coefficient of determination of 0.98 shows the best fit results. The linearregression is used to estimate the required coefficients of dependent variables of the predicted



a) Slump flow results

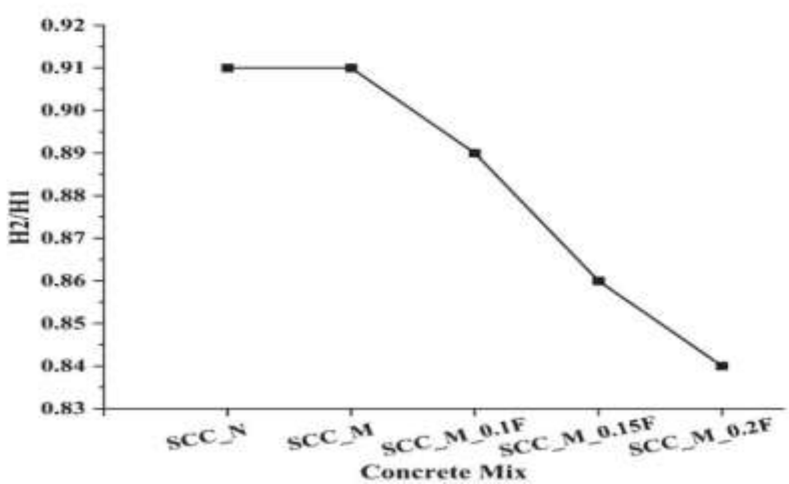
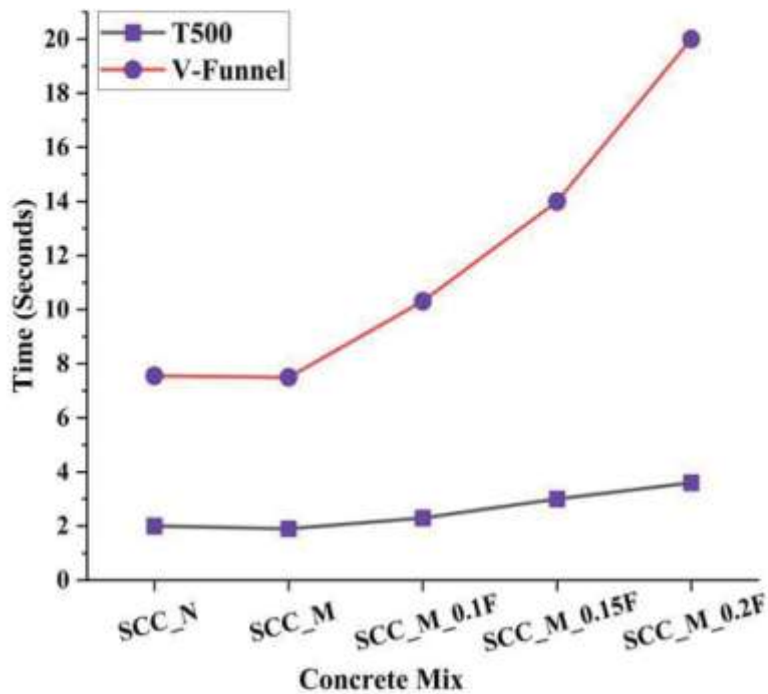


Figure 6. Slump flow test andL-Box test results.

L-Box Results

Linear equation using one or more independent variables. It is observed from Figure 7(b) that the original V-funnel test results of 7.5, 10.31, 14, 20 are predicted as 7.2696, 10.111, 14.999, 19.35, respectively. V-funnel time can be estimated for the PPF M-sand SCC using the T500 test results using the linear regression results are also shown in Figure 7(b).

Figure 8(a) represents the compression strength of all mixes for 7 days and for 28 days. Mix SCC_M showed a good result when compared to the mix SCC_N. Since manufactured sand was well graded and free from the very fine powder content, it influenced the compression strength positively.



a) V-funnel and T500 test results

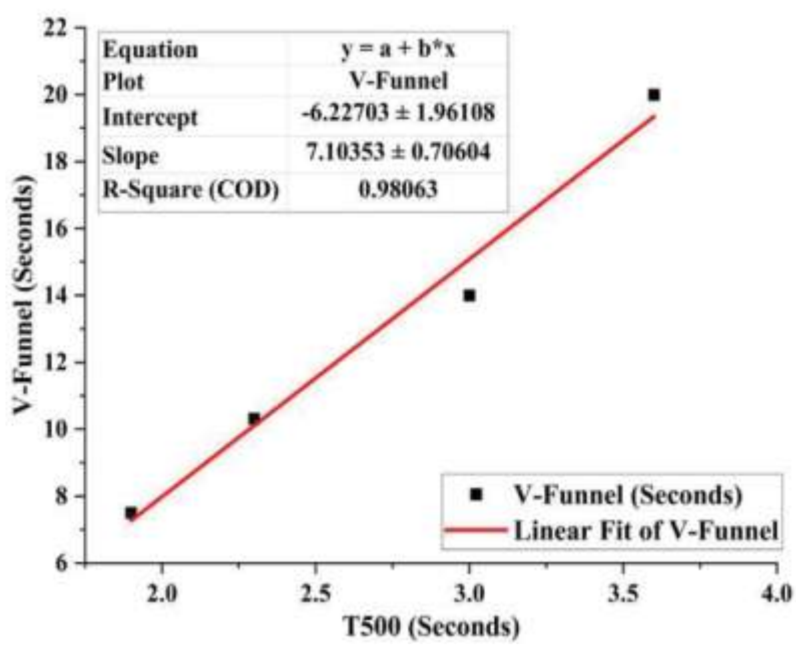
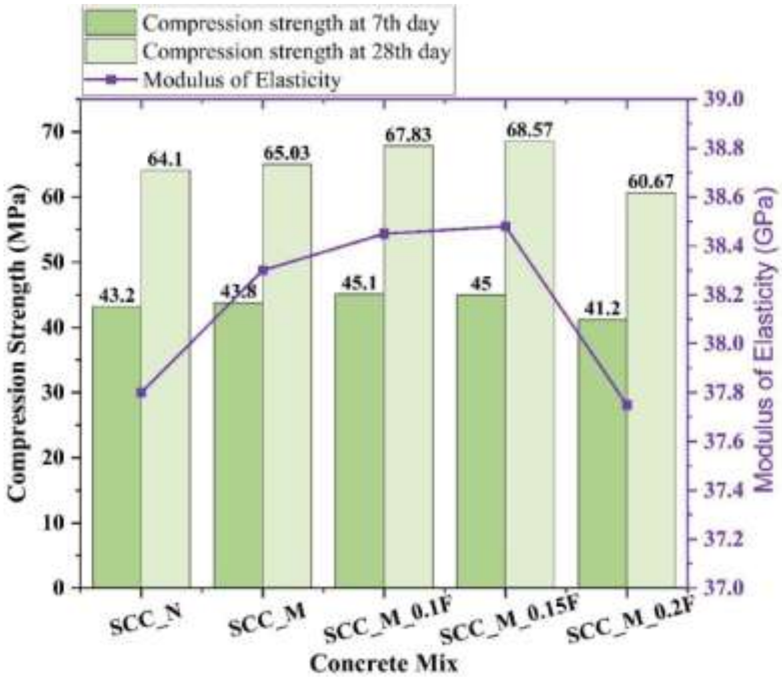


Figure 7 Results of V-funnel, T500 tests and linear plot of the same

b) Linear plot b/w V-funnel and T500 test results

Results show that very small increase in compression strength for the addition of 0.1%and 0.15% fibre content, but it was decreased for 0.2% fibre content. The addition of PPF does not much affect the compression strength of SCC, but a very small increase up to the optimum value of fibres addition was observed. As the fibre contents increases, it forms the cluster and leads to voids formation. The weak interfacial bonding between fibre and cement paste also leads to a decreasein the compression strength of concrete.



a) Compression strength and Modulus of Elasticity

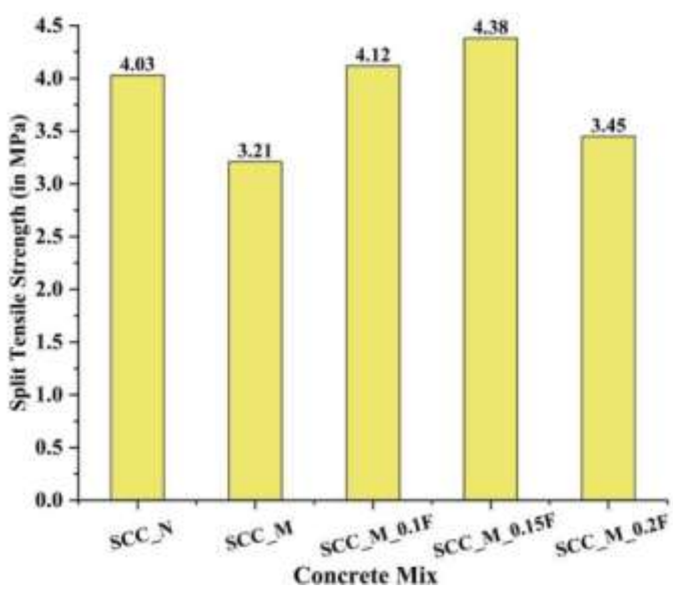


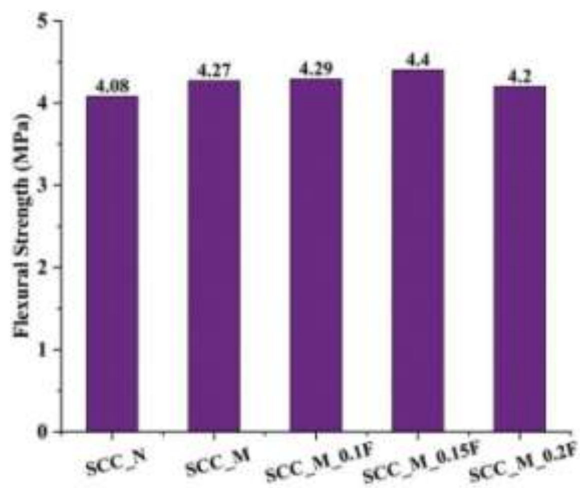
Figure 8. Compression strengthand split tensile test results

B) Split Tensile Strength

The modulus of elasticity of concrete is found to be more for mix SCC_M compared to SCC_N. Andwith PPF content, the modulus of elasticity value was found to be a little higher for the PPF content 0.1% and 0.15%, for 0.2% it is found to be decreased. So, the addition of PPF causes very slight variations to the modulus of elasticity of SCC up to 0.15% content, later modulus of elasticity inversely varied with the percentage increase of PPF.

Figure 8(b) shows the split tensile strength of the considered concrete mixes. It is seen that SCC_M shows 25.5% less strength than SCC_N. M-sand makes the concrete comparatively brittle when compared with the concrete mix made by natural sand. But the addition of fibres with m-sand concrete increased the split tensile strength considerably. The mix SCC_M_0.1F showed 28.35%, and SCC_M_0.15F showed a 36.45% improvement in split tensile strength com- pared with SCC_M. Later, a sudden decrease in the strength was noticed for SCC_M_0.2F, so from this variation it is clear that the split tensile strength of concrete increased with the addition of PPF up to an optimum percentage of addition and later it decreased. As the fibre content increases difficult to reduce the balling effect and uniform distribution of PPF becomes a problem, so the strength reduces.

Water absorption is one of the tests considered to understand the durability of concrete. The concrete comes in contact with the water directly or indirectly. If it is not potable water, then thereis a chance of chemical attack through water absorption, and they may change the properties ofthe concrete.



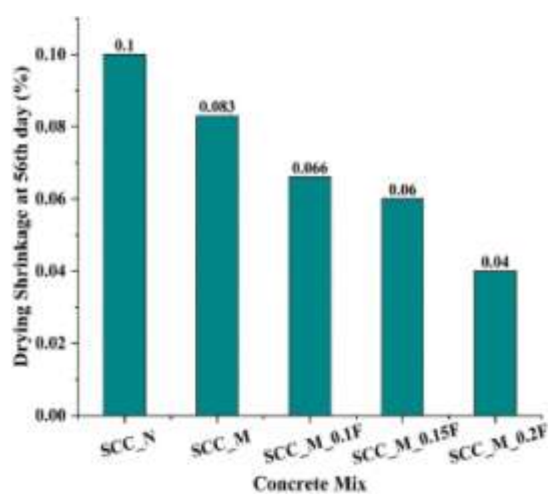


Figure 9. Results of flexural teston plain concrete with fibre andwith

The water present in the pore undergoes a freeze and thaw effect due to the influence of temperature changes, which leads to the cracking of the concrete. These crack developments allow the external agents to penetrate inside the concrete and affect, decrease the durability. So, water absorption test was conducted on a 100 mm cube after 28 days of curing time.

Figure 11(a) shows the water absorption test results after 28 days of curing. Water absorption percentage was found to be less in SCC_M when compared with the SCC_N, but the reduction percentage is considerably less. For SCC_M_0.1F, small reduction in the water absorption percen- tage compared with SCC_M. But when fibre content increased to 0.15%, that is, for SCC_M_0.15F, the water absorption was found to be decreased by 1.15% than SCC_M. After 0.15% of fibre content, the water absorption percentage increased with the increase in the fibre content. Uniform spreading and thorough mixing of the fibres are required to reduce the porosity of the concrete. But with an increase in fibre content, keeping uniformity in mixing fibres becomesa difficult task and clustering of fibres may cause and make the concrete porous. No proper interaction between the fibre and cement paste makes the concrete get crack and correspondingly increases the water absorption of the concrete. Water absorption is directly proportional to the voids present. The optimum percentage of fibre content optimises the pore structure of the concrete and reduces water absorption (Blazy & Blazy, 2021). So, results show that the fibre geometrical properties finely bind the concrete mix with improved properties of SCC.

The ionic moment inside the concrete and reaching to steel leads to the corrosion, so the less crack initiation time shows more penetration of chloride inside the concrete in a similar environment (constant current and concrete strength environment). The initiation and growth of corrosion product on steel embedded in concrete depends on the concrete permeability, cover thickness provided, concentration of the solution used, applied current in the study and the temperature.

CONCLUSION

The following conclusions are drawn from the study done on SCC with natural sand, M-sand andM-sand with PPF on the fresh properties, hardened properties and durability.

- The SCC with M-sand improved the fresh, hardened properties and durability of the concrete.
- Addition of PPF lowers the workability of the SCC considerably. But the optimum percentage of PPF content improved the mechanical properties and durability with good workability.
- PPF percentage not much affected the compression strength of SCC, but after 0.15% of PPF content compression strength was found to be decreased. Split tensile strength, flexural strength and modulus of elasticity also showed slight improvement with the increase in the percentage of PPF.
- The use of M-sand in concrete reduced the drying shrinkage. And with the increase in the PPFpercentage in SCC, the reduction in the drying shrinkage also increased.
- Water absorption and water penetration depth also decreased with an increase in fibre content, but water absorption value increased after 0.15% PPF.
- Chloride and acid resistance improved by adding PPF with PPC cement.
- Study concluded that PPF of 0.15% by volume fraction of concrete improved the mechanical proper- ties and durability of the SCC with better fresh properties. So, this percentage is considered as the optimum value, which increases the resistance against deterioration and corrosion of steel in SCC.
- Optimum PPF addition improved the crack initiation time of concrete due to corrosion pressure.

Despite the obtained results, a more detailed investigation and analysis need to be carried out to understand the durability under thermal effect. Also, the variations in microstructure of concrete should be carefully analysed to understand the change in composition with time due to the environmental effect. Therefore, this study can be extended further to understand strength anddurability properties of SCC with different PPFs to enhance serviceability of structures for engineer- ing applications. With this, study recommends to use M-sand in SCC instead of natural sand to achieve sustainable development in terms of strength and durability.