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Assessment of Polypropylene Fiber for Effect on Fresh and Physical Performance with Durability of Self-Compacted Recycled Aggregate Concrete

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Abstract

Manuscript targets to develop Self-Compacted High-Performance Concrete (SCHPC) by substituting 50% of Natural Aggregate (NA) with Recycled Coarse Aggregate (RCA), along with incorporation of Polypropylene Fiber (PP) Reinforcement at varying volume fractions. Manuscript focuses on the effects of different proportions of polypropylene fibers (0.2%, 0.4%, and 0.6%) when replacing 50% of NA with RCA. The impact of PP reinforcement on various mechanical properties of concrete, like compressive strength, flexural strength, and split tensile strength are examined thoroughly. For durability of SCHPC, Carbonation Resistance, Water Absorption, and Acid Resistance are also explored in the presented paper. Compressive strength of both Natural Aggregate Concrete and Recycled Aggregate Concrete initially increases up to a fiber concentration of 0.4% before declining with increased fiber contents. Identical patterns appear for split tensile strength, where 0.4% fiber content is found to be ideal to optimize strength. At 0.4% PP fiber, minimum carbonation depth for NAC was reported as 2.94, 4.91, and 7.12 percent for 7, 14 and 28 days, respectively. Comparable results are obtained for RAC, for fiber volume proportion of 0.4%. So, the reduction of approximately 16.67% for NAC (28 days) and 17.54% for RAC (28 days) at control mix.

Keywords: Polypropylene Fiber; Recycled Coarse Aggregate; Self Compacted High-Performance Concrete; Carbonation depth; Split Tensile Strength.

1. Introduction

Concrete is a widely used building material in construction industry due to its ease of moldability, workability, and durability properties. Currently, concrete constitutes around 80% of construction materials used worldwide, surpassing other building materials. This growing demand for concrete is driven by modernization of society and advancements in people's daily lives. As the rate of demolition of existing structures increases, consequently rises the generation of Construction and Demolition (C&D) waste. Unfortunately, primary method of disposing of this waste is through landfilling, which leads to a decrease in efficiency of land utilization. Simultaneously, demand for High-Performance Concrete continues to rise over time. As a result of inadequate recycling methods and insufficient environmental regulations regarding disposal, most of these waste materials end up in landfills.

Currently, nearly all nations are grappling with a severe shortage of landfills to accommodate substantial volume of solid waste produced as a result of demolishing aged concrete structures. Estimations suggest that nearly 70% of potential built-up area is yet to be developed, and it is anticipated that total built-up area will increase fivefold by 2030. According to reports from Central Pollution Control Board (CPCB) (2017) in India, country generates approximately 10-12 million tonnes of construction and demolition (C&D) waste each year. Utilization of recycled aggregates, whether in partial or full replacement of natural aggregates, in concrete presents a potential solution to various challenges confronted by society. These include environmental pollution, scarcity of natural resources, and need for waste disposal lands. By incorporating recycled aggregates into concrete, we can address these issues effectively. In last few years, there has been a growing interest in exploring structural applications of recycled coarse aggregates (RCAs). Extensive investigations and research efforts have been dedicated to understanding potential of RCAs in various construction projects. This surge in interest reflects the recognition of RCAs as a viable and sustainable alternative in construction industry. In their research work, Yoda and Shintani, (2014) implemented mid-quality recycled aggregate concrete (RAC) for super structure of a building in Japan. They closely monitored durability properties of RAC over course of one year and obtained promising results. This study highlights potential of using recycled aggregates in concrete construction and suggests that RAC can exhibit satisfactory durability characteristics.

Importance of recycling and reusing concrete waste is emphasized in a report F.D. Maio (2016). This report highlights significance of adopting advanced technologies to promote sustainable practices in construction industry. Additionally, in India, revised regulations of Ministry of Environment (2016) have been implemented, focusing on engaging various stakeholders in recovery, recycling, reuse, and proper management of construction and demolition (C&D) wastes. These regulations aim to enhance sustainable management of C&D wastes and encourage responsible practices among all involved parties. Multiple researches in existing studies have confirmed that recycled aggregates tend to exhibit higher water absorption rates in comparison to natural aggregates. Consequently, it is often suggested that when incorporating recycled aggregates into concrete, there may be a need to increase water content to achieve desired workability E. GUneyisi et al. (2014) and H. Mefteh et al. (1963). These findings emphasize importance of carefully managing water-to-cement ratio when utilizing recycled aggregates to maintain desired workability and ensure overall performance of concrete mixture.

Fiber-reinforced concretes have constantly stood out for their exceptional deformational properties, including high flexural strength, reduced shrinkage, and excellent resistance to abrasion. Through comprehensive analysis of existing literature and a thorough review of latest research by renowned concrete scientists in field of self-compacting concretes (SCCs), coupled with advancements has concluded that current state offers an opportunity to develop SCCs with exceptional physical and technical properties Y. Utepov et al. (2020). This indicates potential for creating self-consolidating concretes that exhibit superior performance and meet demand requirements in various applications. Conventional concrete is inherently brittle, characterized by low tensile strength and limited resistance to crack opening and propagation A.M. Brandt et al. (2008) and Poon C.S. et al. (2004). Concept of fiber reinforcement in concrete was initially introduced by Romualdi and Mandel (1964). They pioneered use of randomly distributed steel fibers in concrete, marking beginning of incorporating fibers to enhance mechanical properties and durability of concrete structures. Addition of fibers provides improved tensile strength and crack resistance, thereby mitigating inherent brittleness of concrete and enhancing its overall performance. Previously published papers have primarily focused on potential of reinforcing traditional dense concrete with fibers, addressing specific challenges. For instance, one study by O.M. Smirnova et al. (2018) investigated enhancement of flexural strength through the utilization of polyolene macrofibres. Another study by F. Mukhtar et. al. (2023) aimed to overcome issue of brittle fracture in high-strength concrete.

Additionally, research has been conducted by R.H. Faraj et. al. (2019), on mechanical, fracture, and durability properties of self-compacting high-strength concrete (SCHSC) containing recycled polypropylene plastic particles (RPPP), both with and without presence of silica fume. These studies contribute to understanding of incorporating fibers and recycled materials in concrete, targeting specific improvements in strength, fracture resistance, and overall performance. Boulekbache et al. (2010) have determined that flexural strength of fiber-reinforced concrete is significantly influenced by distribution and orientation of fibers. Lawyer et al. (2002) have also observed that inclusion of fibers in concrete aids in reducing shrinkage. However, several studies have reported a decrease in workability as a result of fiber addition. Therefore, it is generally recommended to limit fiber content to below 3% J. lie et. al. (2017), L. G. Li et. al. (2018), M. Hsie et. al. (2008) and M. Kamal et. al. (2014) to maintain an acceptable level of workability while still benefiting from enhanced mechanical properties and reduced shrinkage provided by fibers. Kang et al. (2017) found that addition of 0.15% steel fibers can result in flexural performance comparable to that of natural aggregate concrete (NAC) beams in beams composed entirely of recycled coarse aggregates (RCAs). However, Gao and Zhang, (2018) reported that improvement in flexural performance is only observed when steel fiber content exceeds 0.5%, with no noticeable effect below that threshold. Carneiro et al. (2014) investigated indicating an increase in toughness of recycled aggregate concrete (RAC) with inclusion of steel fibers. Furthermore, behavior of RAC with steel fibers exhibited similarities to that of fiber-reinforced NAC under compression. These studies shed light on potential benefits of incorporating steel fibers into RAC to enhance its flexural performance and toughness properties. After considering issues surrounding C&D waste generation and its disposal, as well as impact of high demand for natural aggregates on environment, it becomes crucial to prioritize sustainable construction practices to safeguard the environment and preserve natural resources for future generations.

Based on literature survey, It is observed that different researchers conducted the experiments for variation of RCA from 0% to 100% of replacement, which is a wide range. So, for validation of those experiments it is wise to perform experiments for variation of RCA with 0%, 25%, 50%, and 75% replacement. Among these variations replacement of RCA up to 50% is closer to the obtained results which is convincing. For the step towards sustainable construction, the objective of research is to prioritize the substitute 50% of Natural Aggregate with RCA to produce Self-Compacted High-Performance Concrete (SCHPC) with incorporation of Polypropylene Fiber Reinforcement at various volume fractions of 0.2%, 0.4%, and 0.6%. For High-Performance Concrete production with superior mechanical properties and excellent workability which could also provide the high resistance for aggressive chemical attacks, a concrete mix has been designed.

2. Methodology and Experimental Program

In this study, investigation for performance of fresh properties of concrete when using Recycled Aggregate compared to traditional aggregate, both with and without incorporation of Polypropylene Fiber. Efforts are also done to examine mechanical and durability performance of Self-Compacted High-Performance Concrete (SCHPC). Based on previous studies, it has been observed that addition of fibers to concrete mixture enhances its tensile and flexural performance, reinforces behavior of concrete, and improves its durability. Therefore, main focus of this study is to assess mechanical properties of Self-Compacted High-Performance Concrete (SCHPC) reinforced with Polypropylene Fiber. Primary goal is to quantify and analyze impact of different volume fractions of Polypropylene Fiber on enhancing mechanical properties of SCHPC. Additionally, this research aims to explore optimum content of Polypropylene Fiber that significantly enhances mechanical properties of SCHPC.

3. Material Requirement

Self-Compacted High-Performance Concrete (SCHPC) was prepared using following ingredients:

3.1 Cement and Additives

Grade 43 (Ultratech) Ordinary Portland Cement (OPC 43) was utilized in concrete mix. OPC 43 is a common type of cement widely used in construction due to its reliable performance and availability. It conforms to Indian Standard Specifications for cement (IS 8112: 2013) and possesses adequate strength characteristics for various construction applications. OPC 43 is typically composed of a blend of clinker, gypsum, and other additives to achieve desired chemical and physical properties required for concrete production. Chemical and physical properties of cement are Tabulated in Table-1.

Table.1 Chemical and Physical Composition of Ordinary Portland Cement (Grade 43)

Mineral/Chemical Composition (%)						**Physical Properties**				
C_3S	C_2S	C_3A	C_3AF	f-Cao	f-MgO	Density (g/cm^3)	$f_{cs\cdot f3}$ /MPa	$f_{cs\cdot f7}$ /MPa	$f_{cs\cdot f28}$ /MPa	Fineness (m^3/Kg)
61	18	7.5	8.87	0.89	1.5	3.18	32.6	43.1	54	289

A high-performance additive, superplasticizer (FOSROC Auramix 450) was used as a water-reducing agent in production of concrete mix. Purpose of using this superplasticizer was to improve workability of concrete by reducing amount of water required while maintaining desired consistency and flowability.

The used Superplasticizer (FOSROC Auramix 450) is known for its effectiveness in dispersing cement particles, which helps in achieving better particle suspension and improved flow properties of concrete mixture. It allows for better cohesion and reduces viscosity of mixture, enabling easier placement and compaction of concrete. Specific dosage of superplasticizer used in concrete mix may vary depending on factors such as the desired workability, ambient conditions, and other admixtures present in mix. Superplasticizer is typically added to concrete mix during mixing process to ensure proper dispersion and effectiveness. Physical properties of superplasticizer are mentioned in Table.2.

Table. 2. Physical Properties of superplasticizer.

Type	**Colour**	**Specific Gravity**	**Relative Density**	**Chloride Content**	**Physical State**	**Ph Value**
Poly carboxylic ether Polymer (For type F and G)	Light Yellowish	1.09 – 1.11	1.5 – 25^{0}C	Nil to IS:456	liquid	Minimum 6.0

3.2 Aggregates

In concrete mixture, both Natural Aggregate and Recycled Concrete Aggregate (RCA) were used as coarse aggregates. Natural Aggregate consists of crushed granite stones, which are locally available in market of Gorakhpur, Uttar Pradesh, India. These granite stones are commonly used as a construction material and provide necessary strength and stability to concrete. Grading chart of coarse aggregate on basis of size distribution test as per IS: 383-1970 code is mentioned in Fig.1. Recycled Concrete Aggregate (RCA) was obtained from demolition waste of Central Library of Madan Mohan Malaviya University of Technology, Gorakhpur, Uttar Pradesh. After obtaining the RCA from the source proper procedure is adopted for preparing the samples to use it in concrete mix. The process to obtain the good quality RCA is depicted in Fig. 2.

This RCA is a sustainable alternative to using fresh natural aggregates, as it involves recycling and reusing waste material from demolition process. By incorporating RCA into concrete mixture, it helps reduce demand for new natural aggregates and promotes environmental sustainability. Physical and mechanical properties of Natural and Recycled Aggregate are listed in Table. 3. River sand sourced from local market in Gorakhpur, Uttar Pradesh, was used as fine aggregate in concrete mix. Sand is classified as Zone-II, which indicates that it meets specified requirements for use in concrete construction. Use of appropriate sand with desired grading helps improve workability, strength, and durability of concrete. Size distribution grading curve of fine aggregate (sand) as per IS: 383-1970 code listed below in Fig. 3.

It is noted that specific characteristics and properties of Natural Aggregate, Recycled Concrete Aggregate (RCA), and River Sand may vary based on actual materials used and their respective sources. It is recommended to conduct proper testing and evaluation to determine suitability and quality of these aggregates for concrete mix in specific projects.

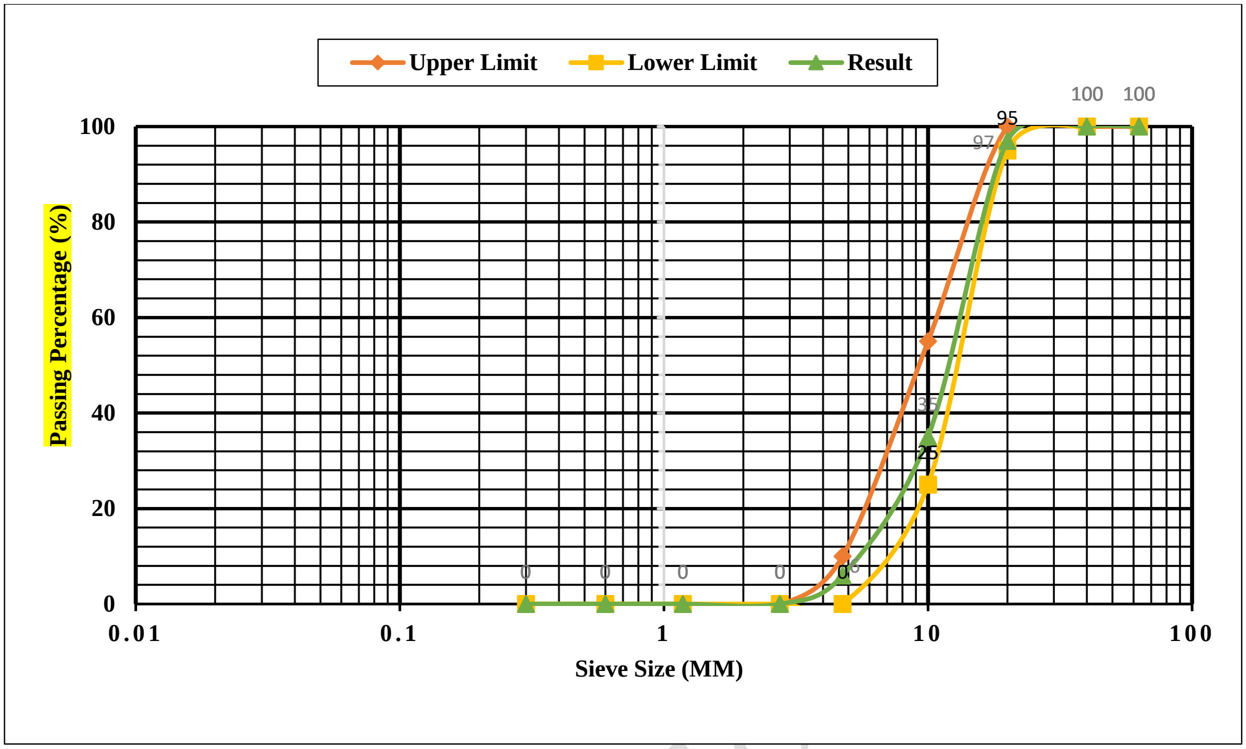

Fig.1. Grading Curve of Coarse Aggregate test as per IS: 383-1970 [14]

Table. 3. Physical and Mechanical Properties of Aggregates

Properties		**Virgin Crushed Granite Aggregate**		**Recycled Concrete Aggregate**	
		Max. Size of Aggregate		Max. Size of Aggregate	
		10MM	**20MM**	**10MM**	**20MM**
Physical Properties					
Specific Gravity		2.78	2.81	2.25	2.33
Water Absorption		0.28	0.23	2.9	2.85
Bulk Density Kg/m^3	Loose	1410	1480	1320	1380
	Rodded	1556	1610	1464	1570
Percentage of Voids	Loose	51	48	45	42
	Rodded	45	42	41	39
Mechanical Properties					
Crushing Value (%)		29.3	28.65	36.87	36.18
Impact Value (%)		20.91	20.24	30.80	29.64
Abrasion Value (%)		30.23	27.18	47.23	38.64

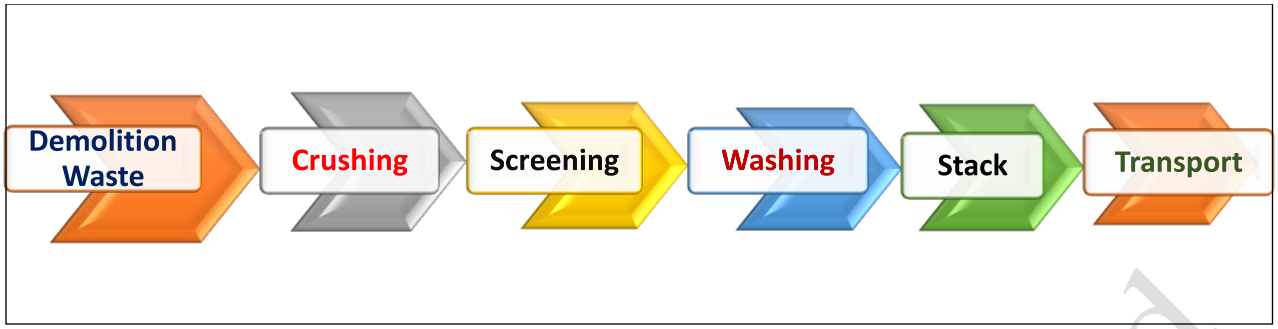

Fig. 2. Process for production of Recycled Concrete Aggregate

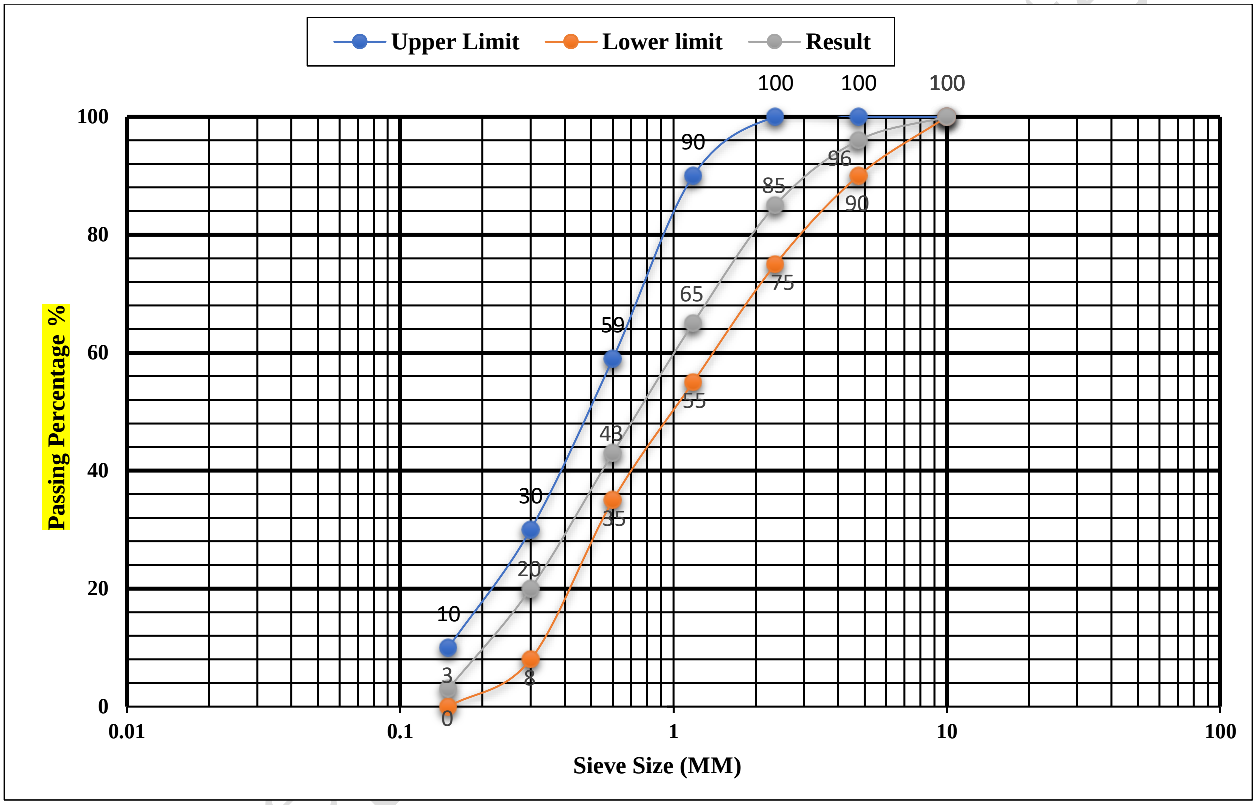

Fig.3. Grading curve of fine aggregate according IS 383:1970 for Zone II

3.3 Polypropylene (PP) Fiber Reinforcement

Reliance Recorn 3S fiber is a kind of polypropylene fiber that is used in production of SCHPC. Polypropylene fibers are commonly added to concrete to enhance its mechanical properties, such as Tensile Strength (TS), Flexural Strength (FS), and Impact Resistance. Reliance Recorn 3S fiber is specifically designed to provide reinforcement and improve overall performance of concrete. These fibers are typically in form of short, discrete strands or fibrillated microfibers. When added to concrete mix, they help control cracking and enhance post-crack behavior of concrete. Exact specifications and characteristics of Reliance Recorn 3S fiber, such as fiber length, aspect ratio, and dosage, may vary based on the specific requirements of your SCHPC mix design and project specifications. Properties of Reliance recorn 3s fiber is mentioned in table 4.

Table. 4. Characteristics Properties of Polypropylene Fiber

Fiber Type	**Shape**	**Length (mm)**	**Effective diameter (μm)**	**Specific Gravity**	**Tensile Strength (GPa)**	**Elongation (%)**	**Young's Modulus (MPa)**	**Melting Point (^{0}C)**	**Alakline Stability**
Polypropylene	Tri-angular	12	25-40	0.90-0.91	4.6	60-90	>4000	160-165	Very Good

3.4 Water

Drinking Tap water which available in Campus laboratory is used in concrete mix with all permissible criterion which was mentioned in Indian Standard (IS) code 456:2000.

IS code 456:2000 provides guidelines for design and construction of reinforced concrete structures. It also specifies permissible limits for various constituents, including water, in concrete mix. Specific requirements for water quality may vary depending on project location and local regulations.

A) Recycled Coarse Aggregate (RCA)

B) Natural Coarse Aggregate (NCA)

C) Superplasticizer

D) Natural Fine Aggregate (Sand)

E) Cement OPC (43Grade)

F) Polypropylene Fiber

Fig. 4 Materials Requirement for Self-Compacted High-Performance Concrete (SCHPC).

3.5 Method of Addition of Fiber

Method of introducing fibers into concrete plays a crucial role in achieving a uniform distribution of fibers throughout concrete matrix and reducing fiber agglomeration. Several investigations, such as AKç K et al. (2015), and Matar et al. (2019) have investigated different techniques for incorporating polypropylene fibers into concrete. Observations from these studies indicate that order in which water and fibers are added can influence mechanical properties of fiber-reinforced concrete. When fibers are added to concrete before water, it facilitates formation of a three-dimensional fiber skeleton within matrix and reduces occurrence of fiber aggregation and voids. This method promotes better dispersion of fibers throughout concrete. On other hand, when casting method is used, where mixing water is added before fibers, dispersion of fibers in concrete is not as effective. This is due to water acts as a binding agent, strengthening already tangled fibers and creating more significant voids. Consequently, mechanical properties of fibers may be compromised.

4. Concrete Mix Design

In this study, several concrete mixes were prepared with different proportions of natural aggregate (NA) and recycled aggregate (RCA), as well as varying volume fractions of polypropylene fibers. Mix designs are prepared for target mean strength of concrete as per the IS 10262:2019.

Following concrete mixes were used:

1. NSCC-100, 0: Natural Aggregate Self-Compacting Concrete (NASCC) with 100% NA and no polypropylene fibers.
2. FNSCC-100, 0.2: Fiber-Reinforced NASCC with 100% NA and 0.2% Proportion of PP fibers.
3. FNSCC-100, 0.4: Fiber-Reinforced NASCC with 100% NA and 0.4% Proportion of PP fibers.
4. FNSCC-100, 0.6: Fiber-Reinforced NASCC with 100% NA and 0.6% Proportion of PP fibers.
5. RSCC-50, 0: Recycled Aggregate Self-Compacting Concrete (RSCC) with 50% RCA and no PP fibers.
6. FRSCC-50, 0.2: Fiber-Reinforced RSCC with 50% RCA and 0.2% Proportion of PP fibers.
7. FRSCC-50, 0.4: Fiber-Reinforced RSCC with 50% RCA and 0.4% Proportion of PP fibers.

Therefore, it is important to carefully consider method of introducing fibers into concrete mix to ensure optimal dispersion and achieve desired mechanical performance. By incorporating fibers before adding water, it is possible to enhance uniform distribution of fibers and improve overall performance of fiber-reinforced concrete.

8. FRSCC-50, 0.6: Fiber-Reinforced RSCC with 50% RCA and 0.6% Proportion of PP fibers

Proportions of each mix are provided in Table 5. Additionally, Fosroc Auramix 450 superplasticizer is used in all mixes to maintain consistent fresh properties of self-compacting concrete (SCC). Superplasticizer should be added at a weight of 1% of the cementitious material to achieve a slump flow between 650- and 730-mm. Superplasticizer is available in a light brownish-colored liquid form.

Concrete mixtures were proportioned with a water-cement ratio of 0.40, following guidelines of BIS (IS: 10262 - 2019). Proportions were selected to achieve a characteristic strength of 30 MPa. Three different volume proportions of PP fibers (0.2%, 0.4%, and 0.6%) were added to both NAC and RAC. It is important to note that both recycled and natural aggregates were utilized in a condition of saturated surface dryness during mixing process, as recommended by Brand et al. (2015) to obtain best outcomes. Tap water from a regular faucet, suitable for drinking, was used in concrete mixing process.

Prior to mixing process, the water adsorption capacity of the RCA must be determined. This could be done by using the water adsorption experiment for RCA. The RCAs are initially dried in this test. After 24 hours of immersion in water, the amount of water absorbed is measured. The aggregates must be dried at 105 degrees Celsius. This leads to the adding of additional water needed for the mix of concrete. Since, RCAs have the more porosity than the natural aggregate for which this addition water is required, and this additional water also affects the workability and durability of concrete.

Table. 5 Mix Proportion of Self Compacted Concrete with use of Polypropylene Fiber (Kg/m^3)

Concrete Reference	Cement	River Sand	Natural Aggregate	Recycled Aggregate	Water	Super Plasticizer	Polypropylene Fiber
NSCC - 100, 0	445	975	737	0	180	3.56	0.00
FNSCC- 100, 0.2	445	975	737	0	180	3.56	4.68
FNSCC - 100, 0.4	445	975	737	0	180	3.56	9.36
FNSCC - 100, 0.6	445	975	737	0	180	3.56	14.04
RSCC - 50, 0	445	975	368.5	368.5	180	3.56	0.00
FRSCC - 50, 0.2	445	975	368.5	368.5	180	3.56	4.68
FRSCC - 50, 0.4	445	975	368.5	368.5	180	3.56	9.36
FRSCC - 50, 0.6	445	975	368.5	368.5	180	3.56	14.04

5. Casting and Curing

In laboratory, a manual concrete mixer is used to mix concrete. Process involves following steps:

1. Water is first combined with superplasticizer to create a homogeneous dispersion. Dosage of superplasticizer is one percent by weight of water to achieve desired slump value of SF3 Flow (660mm-750mm).
2. Recycled coarse aggregate is sprinkled with water a day before use to control production of concrete. It is then covered with a plastic sheet to maintain a high humidity level. Aggregate used is wetted to reduce its water absorption capacity, aiming for a moisture content of 80% of total absorption capacity.
3. Both Natural Aggregate Concrete (NAC) and Recycled Aggregate Concrete (RAC) contain superplasticizer to consider its effect on hardened properties.
4. Mixing process involves adding aggregate, sand, and cement with PP fibers and mixing for two minutes. Then, water is added and mixed again to achieve desired workability.
5. To ensure workability, each type of specimen is subjected to Slump Flow, V-Funnel, and J-ring tests following the specifications of BIS (IS – 10262:2019).
6. After 24 hours, all prepared concrete samples are taken out of mold and placed in a curing tank for specified number of days.

Process of making mix of concrete is given in fig.3.

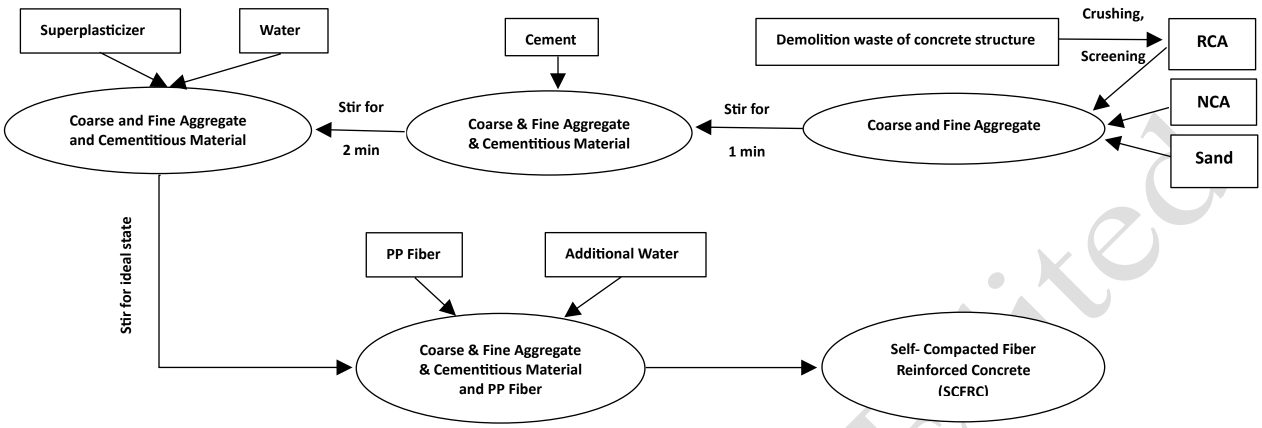

Fig.5. Flow Chart of SCFRC Preparation

For both NAC and RAC, six cube samples (size 150mm x 150mm x 150mm) are prepared with various volume fractions of PP fibers to determine compressive strength (CS) for each sample of mix. Tests are conducted after 7 days and 28 days of the curing period.

Similarly, three flexural strength samples (aspect 500mm x 100mm x 100mm) are prepared for each NAC and RAC with different volume fractions of PP fibers. Flexural strength (FS) test is performed after 28 days of curing.

For split tensile strength (STS), three cylindrical samples are prepared for each NAC and RAC using different volume fractions of polypropylene fibers. Specimen detail of each test were mentioned in the following Table 6.

Table. 6. Specimen detail of casting

Experiment Name	Number of Sample	Size of test samples for concrete mix with max. size of aggregate of 10 and 20mm
Compressive Strength	48	Cube – 150X150X150mm
Split Tensile Strength	24	Cylinder – 150mm dia and 300mm Height
Flexural Strength	24	Beam – 100X100X500mmm
Modulus of Elasticity	24	Cylinder – 150mm dia and 300mm Height

6. Standards Followed for Experimental Setup

CS of concrete cubes is assessed according to guidelines of BIS (IS: 516 - 1959). Concrete cubes with dimensions of 150mm are tested after 7 days and 28 days of curing period. Average CS values of at least three samples for each type of concrete are calculated and reported.

For STS test, cylindrical specimens with dimensions of 150mm in diameter and 300mm in length are prepared. Test is conducted after a 28-day curing period, following specifications of BIS (IS: 5816 - 1999). STS values are determined using a 3000 KN compressive testing apparatus.

FS test, as per BIS (IS: 516 - 1959), is performed after a 28-day curing period on prism samples measuring 500mm x 100mm x 100mm. Flexural strength, represented as modulus of rupture, is calculated using expression described in IS code 516-1959. Average FS values of three samples for each type of concrete are reported.

7. Results and Discussion

7.1 Fresh Properties

Study found that as volume fraction of PP fiber increased, workability of SCC decreased. This is attributed to higher water absorption capacity of RCA compared to NCA. Presence of adhered cement mortar on RCA also made recycled aggregate concrete (RAC) less workable than natural aggregate concrete (NAC) for same water-cement ratio. Similar findings have been reported in previous studies of Chandrasekhar et al. (2018).

When PP fiber is added to NAC or RAC, fresh properties of concrete are affected. Presence of PP fibers forms a matrix that restricts flow of concrete. Fiber particles also adsorb water and bridge gaps between them and concrete mix. It has been observed that concrete with PP fiber has a slump value up to 40% lower. Increased friction between aggregates and fiber particles in mix requires more potential energy for SCC to flow. Study found that SCC containing up to 0.2% volume fraction of PP fiber met requirements for SCC (like flow ability, filling ability, passing ability, Finish ability and Pump ability etc.), but higher dosages did not meet requirements. Table. 7. provides a summary of studies of fresh properties.

Table. 7. Fresh Properties of Self Compacted Recycled Aggregate Concrete with incorporation of PP fiber

Concrete Reference	Slump (mm)	L-Box Test (H$_2$/H$_1$)	V- Funnel Test (s)	T50 – Slump Flow	Remarks
NSCC - 100, 0	722	0.92	05	2.7	Small Bleeding
FNSCC- 100, 0.2	641	0.84	07	4.5	Good SCC
FNSCC - 100, 0.4	596	0.79	13	5.9	Small Stiff
FNSCC - 100, 0.6	553	0.68	16	08	Too Stiff
RSCC - 50, 0	698	0.86	06	2.9	Small Bleeding
FRSCC - 50, 0.2	626	0.82	12	05	Small Stiff
FRSCC - 50, 0.4	573	0.76	15	07	Too Stiff
FRSCC - 50, 0.6	540	0.67	17	8.1	Too Stiff

Based on study data presented in Table 6, here are key findings regarding fresh properties of self-compacted recycled aggregate concrete (SCRAC) containing PP fibers:

1. Slump: Slump values decrease as percentage of PP fiber increases. Mixes with lower PP fiber content, such as NSCC-100,0 and RSCC-50,0, have higher slump values, indicating better workability. However, as PP fiber content increases, slump values decrease. Mixes FNSCC-100,0.6 and FRSCC-50,0.6 have lowest slump values, indicating a decrease in workability.
2. L-Box Test Ratio: L-Box test ratio (H_2/H_1) is a measure of passing ability of SCC. Mixes NSCC-100,0, FNSCC-100,0.2, RSCC-50,0, and FRSCC-50,0.2 have L-Box test ratios between 0.80 and 0.92, indicating good filling and passing ability. However, mixes FNSCC-100,0.4, FNSCC-100,0.6, FRSCC-50,0.4, and FRSCC-50,0.6 have L-Box test ratios below 0.8, indicating poor passing ability.
3. V-Funnel Test: V-Funnel test measures flowability of SCC. Mixes NSCC-100,0, FNSCC-100,0.2, RSCC-50,0, and FRSCC-50,0.2 have flow times between 5 and 12 seconds, which are within acceptable limits for SCC. However, as PP fiber content increases, flow time also increases. Mixes FNSCC-100,0.4, FNSCC-100,0.6, FRSCC-50,0.4, and FRSCC-50,0.6 have flow times greater than 12 seconds, indicating reduced flowability.
4. Bleeding: inclusion of PP fibers significantly reduces bleeding in SCC. Mixes NSCC-100,0 and RSCC-50,0 exhibit small bleeding, indicating improved homogeneity. Large surface area of PP fibers requires more cement paste to cover them, reducing escape of free water onto surface of SCC and improving mixture's homogeneity.

Fig.6. Slump Flow Test on self-compacted Recycled Aggregate Concrete (SCRAC)

Based on above observations, It could be said that better SCC mixes which meets all requirement of SCC are FNSCC-100,0.2 and FRSCC-50,0.2, they contain 0.2% PP fibers by weight in concrete mix. However, mixes with a fraction of PP fiber exceeding 0.2%, such as FNSCC-100,0.4, FNSCC-100,0.6, FRSCC-50,0.4, and FRSCC-50,0.6, do not meet all requirements of SCC (like flow ability, filling ability, Passing ability, Finish ability and Pump ability etc.). Subsequently, it is Suggested to use PP fibers up to 0.2% by weight of concrete mix to achieve good fresh properties in SCRAC.

7.2 Mechanical Behavior of FRRASCC

7.2.1 Density

Figure 7. demonstrates variation in density for both RAC and NAC as volume fraction of fibers increases. In RAC, the density is lower compared to NAC due to increased porosity resulting from

presence of attached mortar on surface of RCA. Mortar adhered to RCA creates voids and reduces overall density of RAC. The graphs also illustrate that as volume fraction of fibers increases, density of concrete decreases. This drop-in density is attributed the difference in specific gravity between PP fibers and concrete mixture. Specific gravity of PP fibers is significantly lower (~ 0.90) than that of concrete mixture.

Therefore, inclusion of PP fibers in concrete mix lowers overall density of mixture.

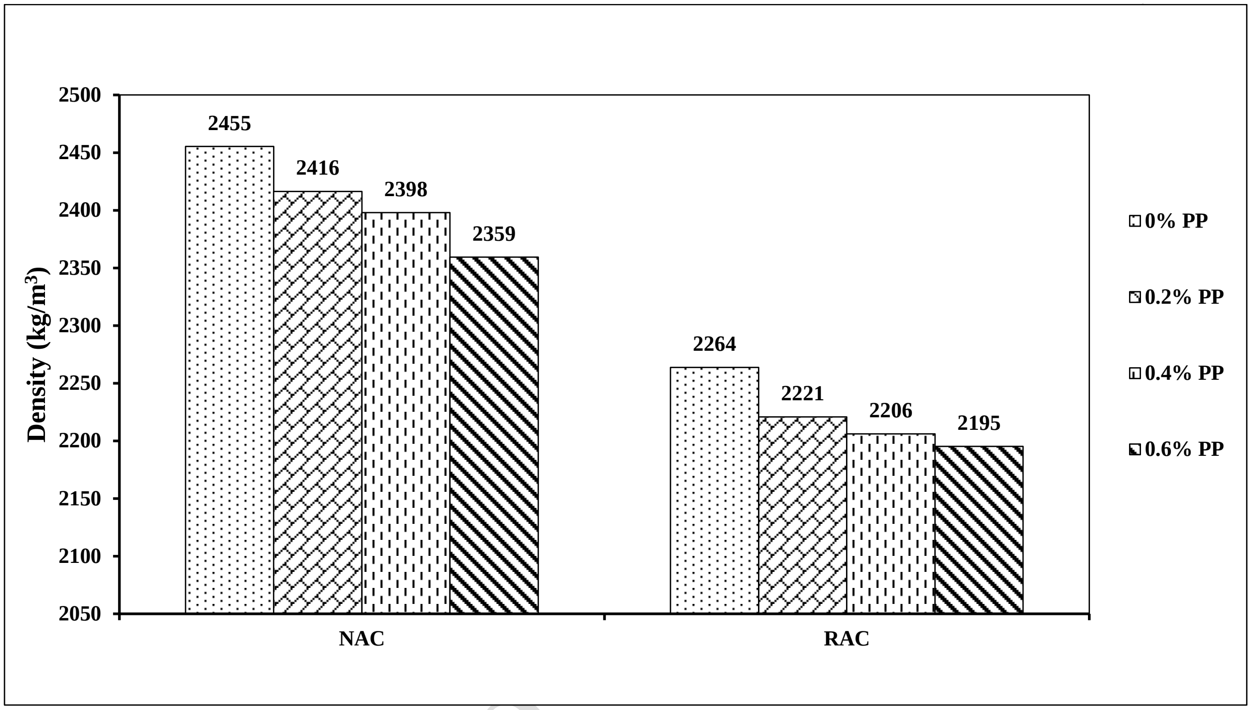

Fig. 7. SCC density varies with PP fibre at various volume fractions.

7.2.2 Compressive Strength (CS)

Fig. 6. illustrates variation in CS values for both RAC and NAC as volume percentage of PP fibers varies. Experimental results indicate that both NAC and RAC exhibit a decrease in CS with addition of PP fibers, reaching a minimum value at a 0.6% fiber addition. On other hand, an increase in CS values is observed with addition of PP fibers up to 0.4%. Maximum CS values for both NAC and RAC are achieved at a 0.4% PP fiber content.

However, it should be noted that modifications in CS due to incorporation of PP fibers are relatively small. Highest increase in CS at a 0.4% PP fiber content is 3.1% for RAC and 4.75% for NAC. Thus, it can be founded that PP fibers have a limited impact on CS measurements, aligning with previous studies S.P. Yap et. Al.((2013) and Z. Bayashi et. al. (1993) that also found minimal effects on CS. Fineness and variable length of primary PP fibres, which create a network serving as a bridge and inhibiting the propagation of micro cracks, are responsible for the behavior of fiber-reinforced concrete (FRC).

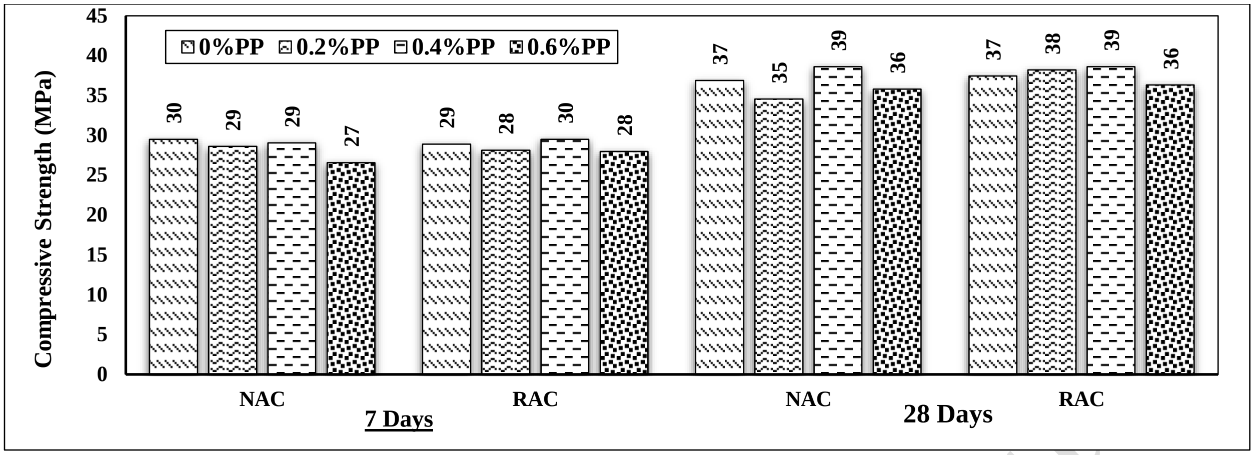

Fig. 8. Impact of PP fibre volume fraction on SCC's CS.

However, when PP fibers are not evenly distributed in concrete due to poor mixing and decreased workability, fiber clusters can create relatively weaker spots that act as voids and are more prone to cracking, resulting in a decrease in CS. Compressive testing machine (CTM) with capacity of 2000 kN was used for compressive strength test.Comparatively, reductions in CS at a 0.6% PP fiber content are 2.9% for NAC and 3.46% for RAC, respectively, in comparison to controlled unreinforced concrete. It is also noteworthy that RAC and NAC exhibit comparable CS. This can be justified by higher water absorption capacity of RCA compared to NCA due to adhered mortar increasing porosity of RCA. As a result, effective W/C ratio for RAC is lower than that for NAC, leading to improved CS.

a) NSCC - 100, 0 b) FNSCC- 100, 0.2 c) FNSCC - 100, 0.4 d) FNSCC - 100, 0.6

e) RSCC - 50, 0 f) FRSCC - 50, 0.2 g) FRSCC - 50, 0.4 h) FRSCC - 50, 0.6

Fig. 9. Crack propagation in NAC and RAC without and with use of PP Fiber.

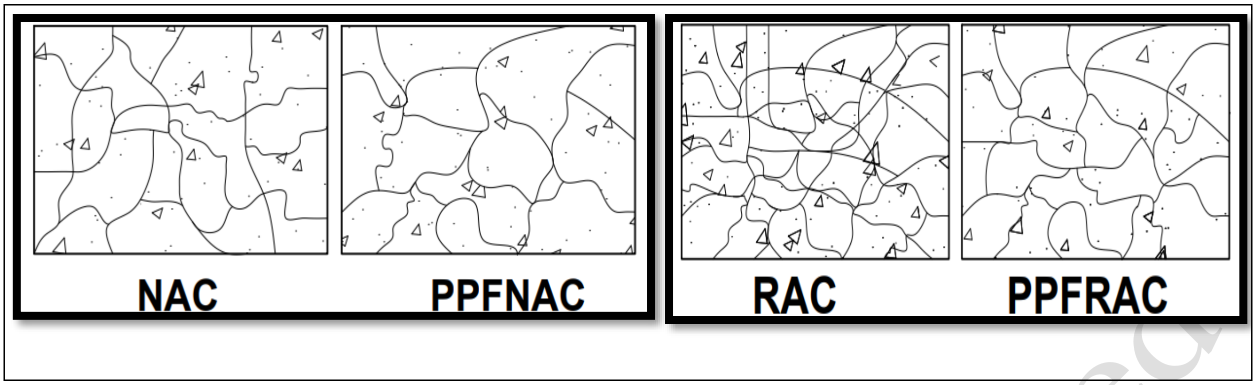

Fig. 10. Cracking Pattern of NAC and RAC with and without use of PP Fiber

The grading curve for RCA shows (Fig. 1) that it lies in the same range, which is applicable for NCA, and guided by the IS:383:1970. The qualities of aggregates for both NCA and RCA are considerably influenced by physical properties such as crushing value, impact value, and Los Angeles abrasion value of aggregates. Additionally, the crushing strength, size and quality of recycled aggregate contributed to designed strength of RAC compared to NAC depends on the origin of parent concrete of recycled aggregated, as indicated by the researchers in their past research A. Akbarnezhad et al. (2013) and K. Kapoor et. Al. (2020).

Above results suggested that addition of PP fibers to concrete enhances its resistance to crack propagation A. Akbarnezhad et al. (2013). Disparity in crack propagation between concretes is clear in Fig. 9 and Fig.10. Volume fraction of PP fibers plays a role in reducing pace of crack propagation by acting as a bridge between mortar, aggregate, and fibers. Fibers also form a matrix with concrete, trapping fiber particles between aggregates and mortar and providing reinforcement. Actual mean value of workability and compressive strength of specimen is defined in the Table 8.

Table .8. Actual mean value of workability and CS of the specimen.

Proportion of Polypropylene Fiber (%)	Actual workability and mean compressive strength of recycled aggregate concrete for different proportion of Polypropylene Fiber Reinforcement					
	Natural Aggregate Concrete (NAC)			Recycled Aggregate Concrete (RAC)		
	Actual Slump Flow (mm)	V – Funnel Flow (S)	Comp. Strength (N/m m^2)	Actual Slump Flow (mm)	V – Funnel Flow (S)	Comp. Strength (N/m m^2)
00	722	05	36.89	698	06	37.46
0.2	641	07	37.54	626	12	38.2
0.4	596	13	38.6	573	15	38.62
0.6	553	16	35.82	540	17	36.32

7.2.3 Split Tensile Strength (STS)

According to Bureau of Indian Standards (BIS) guidelines IS: 5816 – 1999, tensile strength (TS) tests were conducted on both NAC and RAC. Figure 10. demonstrates how STS values vary with different fiber volume proportions. Results indicate that addition of PP fibers significantly increases values for STS. Adding fibers up to a 0.4% Proportion fraction in both NAC and RAC enhances STS values before they start to decline again. maximum value for NAC is 2.805 MPa at a 0.4% fiber volume proportion, which represents a 29.57% improvement over unreinforced control concrete. correspondingly, highest improvement for RAC at a 0.4% fiber volume fraction is 23.79%, with an STS of 2.845 MPa.

After splitting process is complete, fibers act as bridging elements, effectively transferring load from the matrix to fibers and taking additional load from matrix to fibers. This results in higher split tensile (ST) values compared to unreinforced concrete. Improvement in split elasticity of cement also depends on size and shape of PP fibers. Additionally, STS values of RAC are generally higher than those of NAC for same fiber content due to lower effective water-to-cement ratio in a dispersed fiber concrete matrix, stress concentrations are same throughout entire length of fiber.

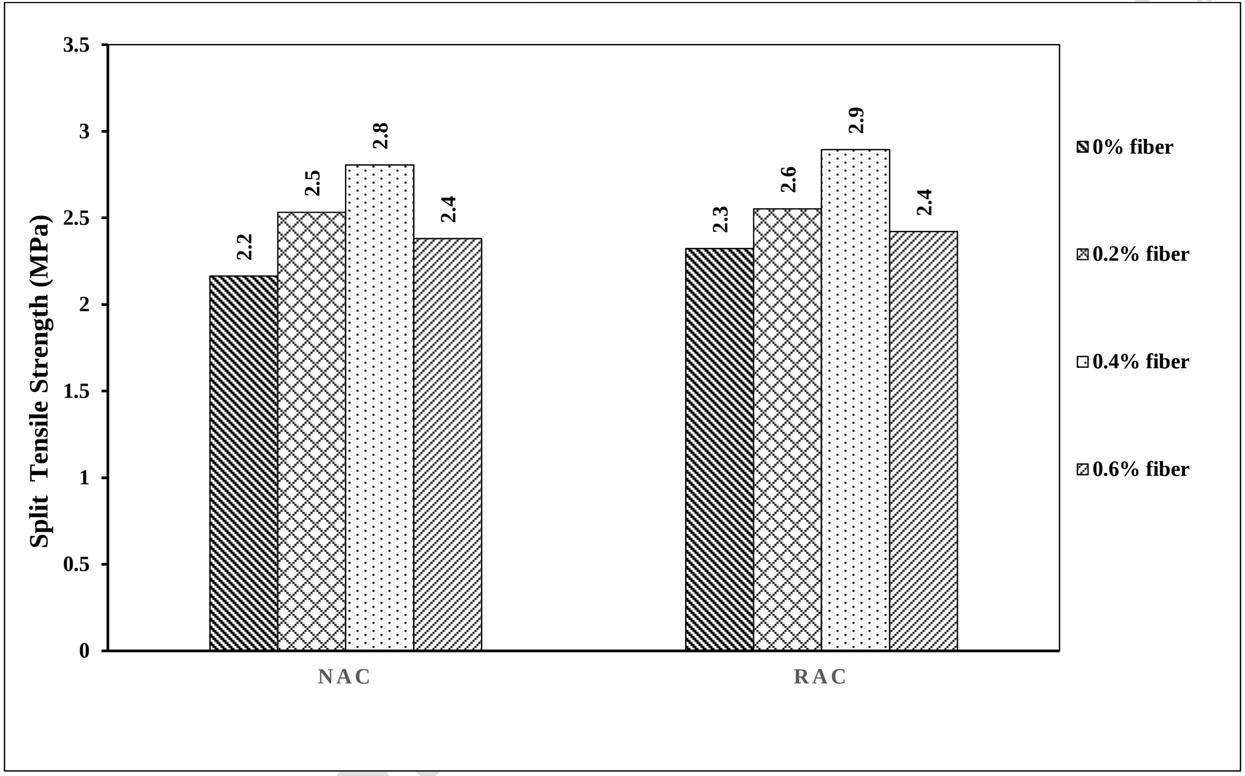

Fig. 11. Impact of different volume proportions of PP fibre on STS.

STS benefits more from addition of PP fibers compared to CS. They exhibit similar behavior, with STS showing positive impacts when PP fibers are added to concrete to promote flexibility by delaying development of tension cracks or preventing their generation. According to Lim and Ozbakkaloglu, (2014), fibres act as crack reducers rather than crack preventers. Fibers are well recognised for their post-cracking behaviour that increases TS. Reinforced concrete demonstrates better performance compared to unreinforced controlled concrete. Fibers are recognized for their post-cracking behavior that increases tensile strength. Figure 11. depicts cracking behavior of controlled concrete with and without PP fiber reinforcement.

7.2.4 Flexural Strength (FS)

Fig. 12. illustrates relationship between volume percentage of PP fiber and FS of both NAC and RAC. FS tests were conducted following guidelines of Bureau of Indian Standards IS: 516 - 1959. Results show that FS initially increases for both NAC and RAC up to a fiber volume proportion of 0.4%. However, beyond this point, as percentage of PP fiber volume content

increases, FS starts to decrease. This contrasts with behavior observed in CS, where addition of fibers resulted in an increase in strength.

In comparison to unreinforced concrete, which has a maximum FS value of 3.5 MPa, NAC achieves a maximum value of 3.8 MPa, representing a 10.8% improvement. Similarly, RAC reaches a maximum FS of 4.1 MPa compared to 3.7 MPa for unreinforced concrete, resulting in a 12.7% increase. FS values for RAC are slightly higher than those for NAC, consistent with findings for CS and STS values. Overall, addition of PP fibers has a positive impact on FS of both NAC and RAC, up to a certain fiber volume proportion. However, beyond this point, FS starts to decrease. It's important to consider optimal fiber content to achieve desired flexural performance in concrete.

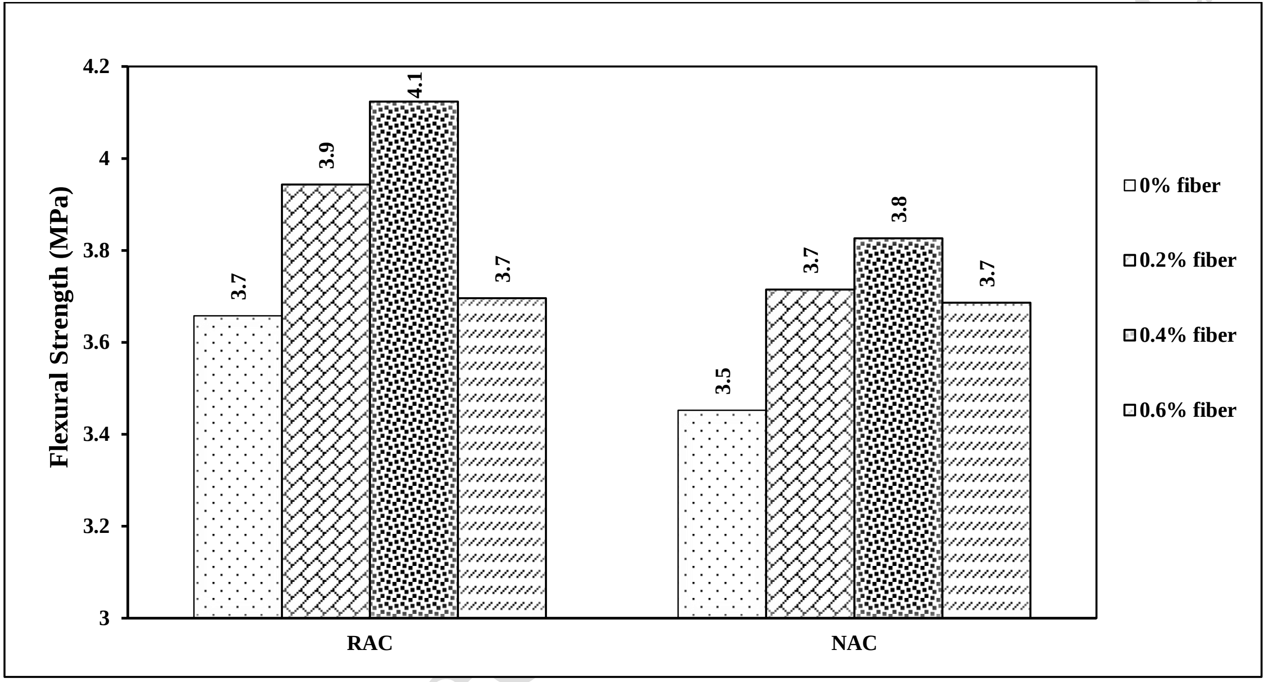

Fig. 12. Variations in PP fiber volume proportion influence both NAC and RAC's FS.

7.2.5 Modulus of Elasticity

Figure 13. presents relationship between volume fraction of pp fiber and Modulus of Elasticity (MoE) for both NAC and RAC. It is observed that both NAC and RAC follow a similar trend as volume percentage of PP fibers changes. Results indicate that as fiber volume percentage increases, MoE decreases. This is attributed to presence of a greater number of microcracks along length of cracks and increased fiber content. Both NAC and RAC exhibit similar MoE values for control mix, indicating comparable stiffness.

However, when maximum fiber volume percentage of 0.6% is reached, there is a reduction in MoE value. Specifically, for NAC, there is a 20.18% decrease in MoE, while for RAC, decrease is 34.13%. This reduction in MoE can be attributed to weakest link for cracking, which is interface between old adhering mortar and the aggregates. Most of cracks tend to follow this interfacial transition zone (ITZ). It is important to note that addition of PP fibers can lead to a decrease in MoE of both NAC and RAC. However, specific decrease in MoE varies between two types of concrete.

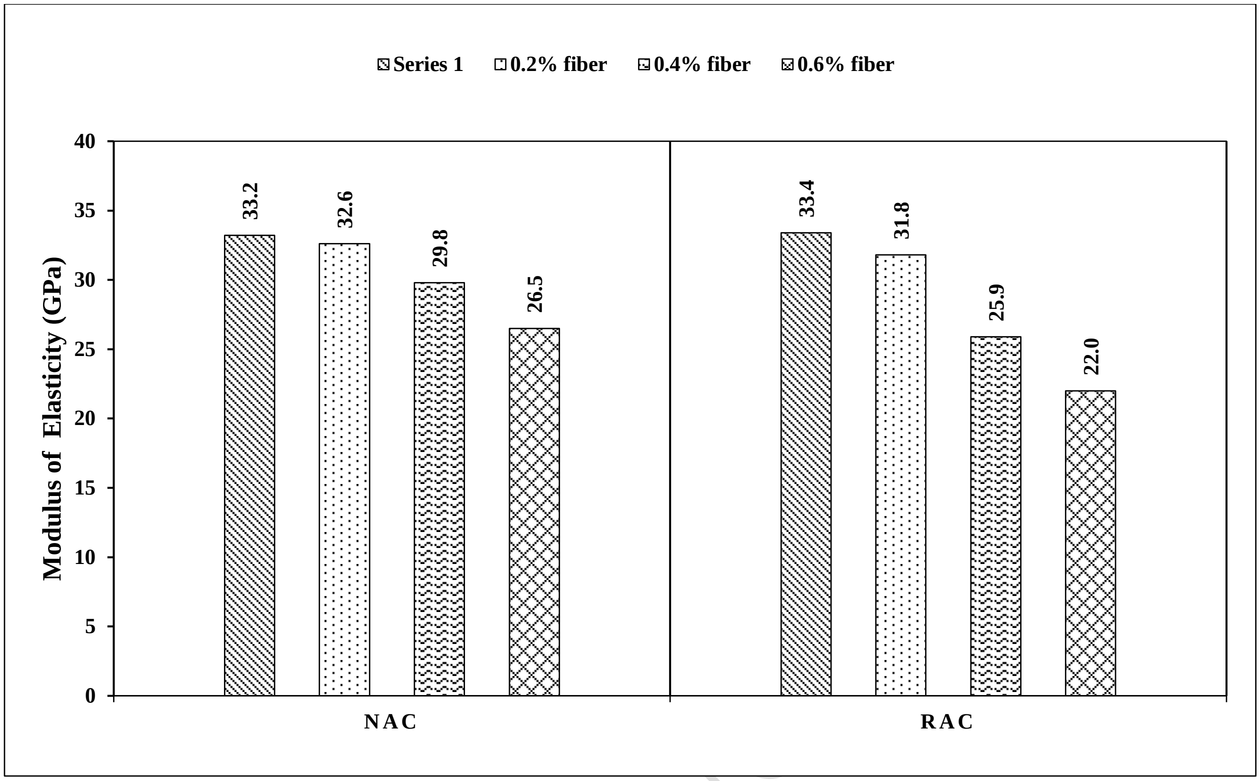

Fig. 13. Impact of Different volume proportions of PP Fiber on MoE.

7.3 Durability of Concrete

Concrete durability is an important aspect that can be indirectly measured by water absorption. Water contains chemicals that can adversely affect properties of concrete when they interact with its constituents. One of durability concerns is freeze-thaw effect caused by presence of additional water in concrete's pores during temperature changes. This effect leads to expansion and contraction of concrete, resulting in cracks and reduced durability.

7.3.1 Water Absorption (WA)

In order to evaluate water absorption characteristics, PP Fibers were subjected to a water absorption test for different durations (seven days, fourteen days, and 28 days) with varying volume proportions. Water absorption test for concrete is conducted as per IS 1199:1959. This code provides guidelines for determining water absorption characteristics of concrete specimens. Fig.14. illustrates outcomes of water absorption test. Generally, it is observed that ability of fiber-reinforced concrete to adsorb water decreases as volume fraction of PP fibers increases up to 0.4% in both NAC and RAC.

Addition of PP fibers enhances tensile characteristics of concrete, thereby preventing initiation and propagation of early cracks. However, it is evident that adding more than 0.4% proportion of PP fibers to concrete leads to fiber clustering. This clustering phenomenon can cause formation of numerous microcracks in both NAC and RAC, consequently increasing water absorption of concrete, particularly in SCC. Therefore, it is crucial to carefully consider volume proportion of PP fibers in order to achieve desired improvement in concrete properties without compromising its durability and water absorption characteristics.

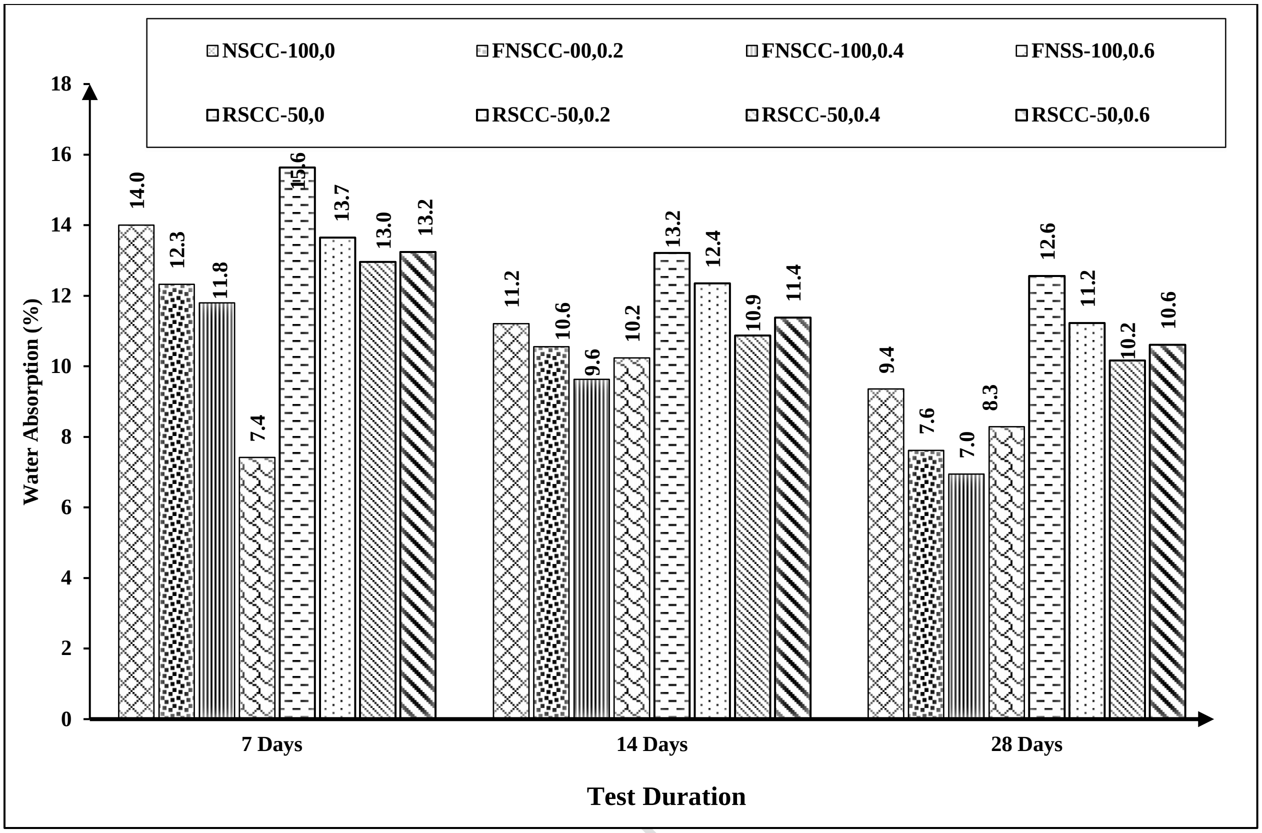

Fig. 14. Impact of various volume proportion of PP fiber on water absorption.

7.3.2 Acid Resistance

Indian Standard codes do not specifically provide guidelines for acid resistance tests for concrete. However, there are internationally recognized standards that can be followed to assess the acid resistance of concrete. One such commonly used standard is ASTM C267. In study on acid resistance, hydrochloric acid (HCl) was utilized as an acid to assess resistance of concrete samples with varying volume proportions of PP fibers. Acid resistance test involved measuring loss in concrete mass caused by acidic attack of HCl on specimens for different durations (7 days, 14 days, and 28 days) for each mix proportion of both NAC and RAC. Results of acid resistance test are presented in Fig.15. Findings clearly indicate addition of PP fibers at volume proportion up to 0.4% for both NAC and RAC significantly reduce weight loss caused by HCl acid. This can be attributed to use of PP fibers, which effectively slow down development and propagation of early fractures and decrease porosity of concrete. Consequently, penetration of HCl acid into concrete is hindered, preventing rapid deterioration.

In acidic environments, HCl acid reacts with calcium aluminate and calcium hydroxide, leading to erosion of concrete. Rate at which HCl acid penetrates concrete and reaches these components determines speed of erosion. By incorporating PP fibers, concrete's resistance to acid attack is improved.

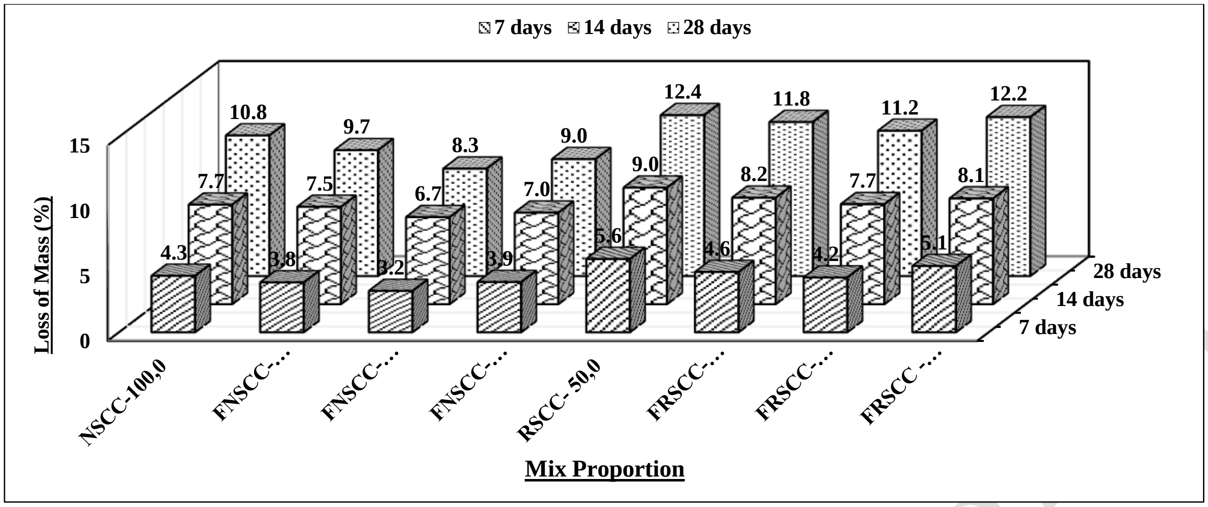

Fig. 15. Influence of various PP fibre volume fractions on acid resistance.

However, it is important to note that at higher PP fiber dosages (0.6%), density of SCC significantly decreases due to reduced workability. This decrease in density can result in increased weight loss from HCl acid attack. Therefore, it is crucial to carefully consider dosage of PP fibers in order to achieve optimal acid resistance while maintaining the desired workability and density of concrete.

7.3.3 Carbonation Resistance Test

The carbonation depth test, as per the ASTM standard, specifically ASTM D7705, provides a method for determining the depth of carbonation in hardened concrete. This test helps assess the carbonation resistance of concrete and evaluate its durability in carbonation-prone environments. Carbonation depth of concrete is influenced by percentage of PP fibers in both NAC and RAC. As proportion of PP fibers increases from 0% to 0.4%, carbonation depth of concrete decreases. Furthermore, carbonation depth continues to decrease as percentage of PP fibers increases up to 0.6%. It is observed that concrete containing PP fibers exhibits less carbonation compared to control mix without fibers.

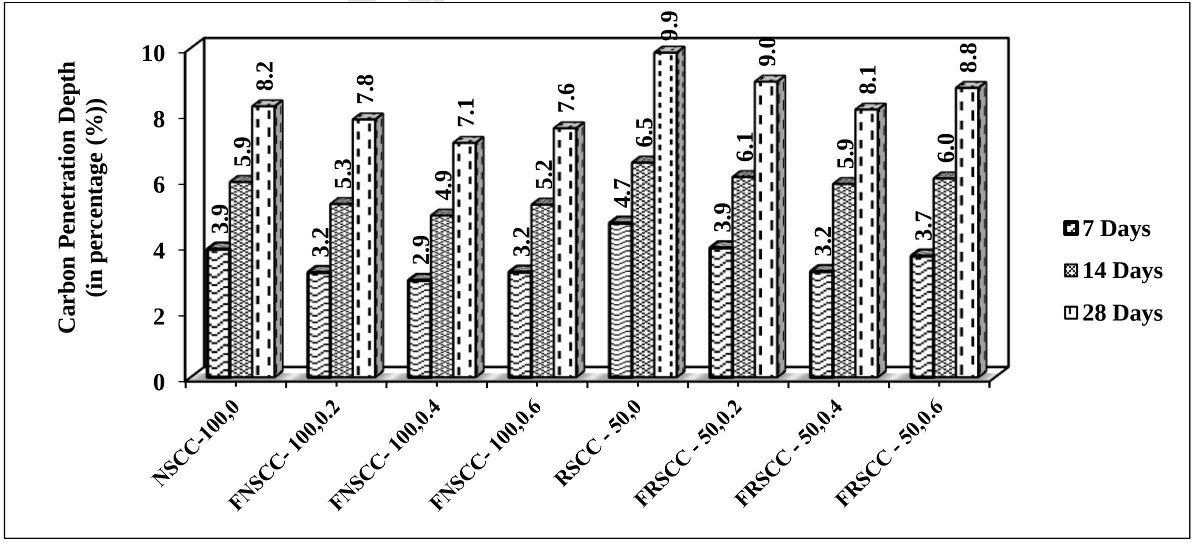

Fig. 16. Influence of different volume proportion of PP fiber on Carbonation Resistance.

In specimen, at a volume percentage of 0.4% PP fiber, minimum carbonation depth for NAC was reported as 2.94%, 4.91%, and 7.12% at 7 days, 14 days, and 28 days, respectively. Similar results were obtained for RAC, where minimum carbonation depth was 3.21%, 5.87%, and 8.1% at 7 days, 14 days, and 28 days, respectively, when fiber volume proportion was 0.4%. This represents a reduction of approximately 16.67% for NAC (28 days) and 17.54% for RAC (28 days) compared to control mix.

Inclusion of PP fibers in concrete obstructs diffusion channel for CO_2, increasing resistance to CO_2 diffusion and slowing down carbonation process. This is illustrated in Fig. 16, which shows correlation between volume percentage of PP fiber and carbonation depth. However, at higher dosages of PP fiber (0.6%), fibers can prevent cement paste from filling voids in microstructure, increasing internal porosity and potentially creating a new pathway for CO_2 to enter concrete structure. This can accelerate carbonation process. It is important to consider dosage of PP fibers to achieve desired balance between carbonation resistance and other concrete properties.

The addition of these fibers outcomes with novel improvement in splitting tensile capacity, flexural capacity, toughness, and ductile failure of concrete owing to their small microstructural size which retards the origination and expansion of early micro-cracks inside the concrete matrix. Novelty has been noted in comparison to NAC, as these fibers in RAC are more valuable in several aspects. Firstly, RAC matrix is weak and the bonding between cement and aggregate phase is poor therefore the tensile strength and durability of RAC is more pronounced than NAC, as these properties are enhanced by PP fibers. Which further results in preventing the formation and propagation of micro-cracks. These impacts of fibers in RAC were also ratified in another research works (Gao et. al. , (2020)). Secondly, owing to the glued mortar, RCA develops higher shrinkage cracks in RAC. The deployment of these PP fibers benefits RAC by restricting the expansion of shrinkage cracks, which results in a durable concrete.

8. Conclusions

In the presented manuscript investigation for impact of PP fibers on properties of NAC and RAC through experimental assessment using fiber integration at 0.2%, 0.4%, and 0.6% in both types of concrete have been done. The key findings of this study can be summarized as follows:

1. PP fibers significantly reduce workability of concrete by increasing friction between particles. RAC is less workable than NAC due to larger water absorption capacity of recycled coarse aggregate caused by old mortar adhering to its surface.
2. Presence of PP fibers obstructs bleeding and segregation in concrete mix, as fibers flocculate with aggregates and mortar, restricting their movement and adsorbing some water.
3. RAC has a lower density compared to NAC, and addition of PP fibers further reduces density of RAC due to lower specific gravity of fibers.
4. CS of both NAC and RAC initially increases up to a fiber content of 0.4% but starts to decline with higher fiber contents. This is attributed to higher stresses present at ends of fibers in a dispersed fiber concrete matrix.
5. Similar trends are observed for split tensile strength (STS), where optimal fiber content for enhancing strength is found to be 0.4%.
6. Addition of PP fibers greatly improves aspects of durability such as water absorption, acid resistance, and carbonation depth.

7. Overall, PP fibers have a positive impact on mechanical performance of SCC, regardless of whether it is NAC or RAC.

Study concludes that use of RCA in construction projects is increasing, and successful incorporation of PP fibers into concrete enables creation of PP Fiber Reinforced Self-Compacted Concrete (PFRRASCC). Use of RCA is expected to be a significant development in construction, benefiting both environment and ecosystem in a sustainable manner.

Abbreviations

C&D	Construction and Demolition.
CS	Compressive Strength.
FS	Flexure Strength.
HPC	High Performance Concrete
NA	Natural Aggregate
NAC	Natural Aggregate Concrete
PP Fiber	Polypropylene Fiber
PPFNAC	Polypropylene Fiber Natural Aggregate Concrete
PPF RAC	Polypropylene Fiber Recycled Aggregate Concrete
PFRRASCC	PP Fiber Reinforced Self-Compacted Concrete
STS	Split Tensile Strength
SCC	Self-Compacted Concrete
SCHPC	Self-Compacted High-Performance Concrete.
RAC	Recycled Aggregate Concrete
NASCC	Natural Aggregate Self-Compacting Concrete
NSCC	Natural Aggregate Self-Compacting Concrete
FNSCC	Fiber-Reinforced Natural Aggregate Self-Compacting Concrete
RSCC	Recycled Aggregate Self-Compacting Concrete
FRSCC	Fiber-Reinforced Recycled Aggregate Self-Compacting Concrete

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Declaration

Competing Interests

In the presented manuscript, authors explicitly state that they have no potential conflicts of interest related to this study.

References

Akbarnezhad A., Ong K. C. G., Tam C.T., and Zhang M. H. (2013). "Effect of the parent concrete properties and crushing procedure on the properties of coarse recycled aggregates." . *Journal of Materials in Civil Engineering,* 25(1), 1795-1802. http://dx.doi.org/10.1061/(ASCE)MT.1943-5533.0000789

Brandt. A.M. (2008). "Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering". *Compoite Structures*, 86(1), 3–9. https://doi.org/10.1016/j.compstruct.2008.03.006

Ansari, Md I. and Kumar A. (2019). "Bending analysis of functionally graded CNT reinforced doubly curved singly ruled truncated rhombic cone." *Mechanics Based Design of Structures and Machines, 47(1),* 67-86. https://doi.org/10.1080/15397734.2018.1519635

Brand A.S., Roesler J. R. and Salas A. (2015). "Initial moisture and mixing effects on higher quality recycled coarse aggregate concrete". *Construction and Building Materials,* 79(1), 83-89.

http://dx.doi.org/10.1016/j.conbuildmat.2015.01.047

Boulekbache B., Hamrat M., Chemrouk and Amziane S. (2010). "Flowability of fibre-reinforced concrete and its effect on the mechanical properties of the material". *Construction and Building Materials*, 24(1), 1664–1671. https://doi.org/10.1016/j.conbuildmat.2010.02.025

Central Pollution Control Board (CPCB). (March 2017). "Guidelines on environmental management of C&D wastes, Ministry of Environment, Forests & Climate Change". *India.* Guidelines_Final_C&D_March_2017.pdf (py.gov.in)

Das C. S., Dey T., Mukharjee B. B. and Kumar J. (2018). "Pereformance evaluation of polypropylene fiber reinforced recycled aggregate concrete". *Construction and Building Materials*, 189(1), 649-659. https://doi.org/10.1016/j.conbuildmat.2018.09.036

Gao D. and Zhang L. (2018). "Flexural performance and evaluation method of steel fiber reinforced recycled coarse aggregate concrete". *Construction and Building Materials*, 159(1), 126-136. https://doi.org/10.1016/j.conbuildmat.2017.10.073

Güneyisi E., Gesoğlu M. and Yazici H. (2014). "Effect of surface treatment methods on the properties of self-compacting concrete with recycled aggregates". *Construction and Building Materials*, 64(1), 172–183. https://doi.org/10.1016/j.conbuildmat.2014.04.090.

Maio F.D.,Rem P., Lofti S. and Serranti S. (2016). *"Advanced technologies for the production of cement and clean aggregates from construction snd demolition waste. ."* . Retrieved from 2016. https://www.researchgate.net/publication/309309338_Cement_and_clean_aggregates_from_cdw_The_c2ca_project.

Mukhatar F. and El-Tohfa A. (2023). "A review on fracture propagation in concrete: Models, methods, and benchmark tests". *Engineering Fracture Mechanics, 281(1), 109100.* https://doi.org/10.1016/j.engfracmech.2023.109100

Mefteh H., Kebaïli O., Berredjem L. and Arabi N. (2013). "Influence of moisture conditioning of recycled aggregates on the properties of fresh and hardened". *concrete, Journal of Cleaner Production*, 54(1), 282–288. https://doi.org/10.1016/j.jclepro.2013.05.009

I.S. 2386-Part-IV. (Reaffirmed in 2021). *"Indian Standard Method of Test fpr Aggregate for Concreet."*. New Delhi.: Bureau of Indian Standards. https://law.resource.org/pub/in/bis/S03/is.2386.4.1963.pdf

I.S. 383-2016. (2016). *"Indian Standard Specification of Coarse and fine Aggregate fro Natural Sources."*. New Delhi.: Bureau of Indian Standards. https://law.resource.org/pub/in/bis/S03/is.383.1970.pdf

I.S. 456-2000. (Reaffirmed in 2021). *"Indian Standard plain and Reinforced concrete code of practice."*. New Delhi.: Bureau of Indian Standards. https://law.resource.org/pub/in/bis/S03/is.456.2000.pdf

I.S. 516 - 1959. (Reaffirmed in 2018). *Indian Standard method of tests for strength of concrete.* New Delhi: Bureau of Indian Satndards,. https://law.resource.org/pub/in/bis/S03/is.516.1959.pdf

I.S. 5816-1999. (Reaffirmed in 2004.). *Indian Standard Splitting Tensile Strength of Concrete - method of Test.* New Delhi: Bureau of Indian Standards,. https://law.resource.org/pub/in/bis/S03/is.5816.1999.pdf

I.S. 8112-2013. (2013). *"Indian StandardSpecification 43 Grade Ordinary*

Portland Cement Specification.". New Delhi.: Bureau of Indian Standards. https://law.resource.org/pub/in/bis/S03/is.8112.1989.pdf

I.S.10262-2019. (2019.). *Indian standard recommended guideline for Concrete Mix Design* .,. New Delhi,: Bureau of Indian Standards. https://law.resource.org/pub/in/bis/S03/is.10262.2009.pdf

I.S. 1199 : 1959 (Reaffirmed in 2018), *Methods of Sampling and Analysis of Concrete.*, New Delhi,: Bureau of Indian Standards. https://ia903000.us.archive.org/21/items/gov.in.is.1199.1959/is.1199.1959.pdf

India., M. o. (2016.). *"The Gazette of India, Part - II, Section-3, Sub-Section (ii) Forest and climate change."*. Retrieved from http://www.moef.gov.in/sites/default/files/C%20&D%202016.Pdf,

Ahmad J., Zaid O. Sharaky I. A., Aslam F., Martínez-García R., Alharthi Y. M., Ouni. M. H. E. and Tufail R. F. (2021). "Mechanical properties and durabilty assessment of nylon fiber reinforced self-compacting concrete.". *Journal of Engineered Fibers and Fabrics,*16(1), 15589250211062833. https://doi.org/10.1177/15589250211062833

Li J., Niu J., Wan C., Liu X. and Jin Z. (2017). "Comparison of flexural property between high performance polypropylene fiber reinforced lightweight aggregate concrete and steel fiber reinforced lightweight aggregate concrete". *Construction and Building Materials*, 157(1), 729–736. http://dx.doi.org/10.1016/j.conbuildmat.2017.09.149

Carneiro J.A., Lima P. R. L., Leiti M. B. and Filho R. D. T. F. (2014). Compressive stress–strain behavior of steel fiber reinforced-recycled aggregate concrete. *Cement and Concrete Composites*, 46(1), 65–72. https://doi.org/10.1016/j.cemconcomp.2013.11.006

Jindal A. and Ransinchung G.D. (2022), "Behavioural Study of Incorporation of Recycled Concrete Aggregates and Minerals Admixtures in Pavement Quality Concrete". Civil Engineering Infrastructures Journal, 55(2), 351-372. https://doi.org/10.22059/ceij.2022.326564.1766

Romualdi J.P. and Mandel J. A. (1964). "Tensile strength of concrete affected by uniformly distributed and closely spaced short lengths of wire reinforcement". *Journal of American Concrete Institute*, 61(6), 657–672. 10.14359/7801

Lawler J.S., Zampini D. and P. Surendra. (2002). "Permeability of cracked hybrid fiber reinforced mortar under load". *Journal of American Concrete Institute Materials Journal*, 99(4), 379–385. 10.14359/12220

Kapoor K., Singh S. P. and Singh B. (2020). " Permeability of self-compacting concrete made with recycled concrete aggregates and Portland cement-fly ash-silica fume binder.". *Journal of Sustainable Cement - Based Materials,*10(1), 1–27 . http://dx.doi.org/10.1080/21650373.2020.1809029

Yoda K. and Shintani A. (2014). "Building application of recycled aggregate concrete for upper-ground structural elements". *Construction and Building Materials*, 67(1), 379–385. https://doi.org/10.1016/j.conbuildmat.2013.12.096

Akça K.R., Çakir Ö. and İpek M. (2015). "Properties of polypropylene fiber reinforced concrete using recycled aggregates". *Construction of Building Materials, 98(1)*, 620–630. https://doi.org/10.1016/j.conbuildmat.2015.08.133

Li L.G., Chu S. H., Zeng K. L., Zhu J. and Hawan A. K. H. (2018). "Roles of water film thickness and fibre factor in workability of polypropylene fibre reinforced mortar". . *Cement and Concrete Composites, 93(1)*, 196–204.

https://doi.org/10.1016/j.cemconcomp.2018.07.014

Hsie M., Tu C.and Song P. S. (2008). "Mechanical properties of polypropylene hybrid fiber-reinforced concrete". *Materials Science and Engineering: A*, 494(1), 153–157. http://dx.doi.org/10.1016/j.msea.2008.05.037

Kamal M.M., Safan M. A., Etman Z. A. and Kasem B. M. (2014). "Mechanical properties of self-compacted fiber concrete mixes". *Housing and Building National Research Center HBRC Journal*, 10(1), 25–34. https://doi.org/10.1016/j.hbrcj.2013.05.012

Matar P. and Zéhil G. P. (2019.). "Effects of Polypropylene Fibers on the Physical and Mechanical Properties of Recycled Aggregate Concrete". *Journal of Wuhan University of Technology-Material. Sci. Ed.,* 34(1), 1327-1344 . http://dx.doi.org/10.1007/s11595-019-2196-6

Singh N. and Singh S. P. (2018). "Validation of carbonation behavior of self compacting concrete made with recycled aggregates using .". *European Journal of Environmental and Civil Engineering,* 24(1), 2187-2210. https://doi.org/10.1080/19648189.2018.1500312

Smirnova O.M. and Kharitonov's A. (2018). "Strength and strain-stress properties of fiber concrete with macro-fiber on the basis of polyolefins". *Stroitel nye Materialy.*, 766(12), 44 – 48. http://dx.doi.org/10.31659/0585-430X-2018-766-12-44-48

Ozbakkaloglu T. and Lim J. C. (2014). "Confinement model for FRP confined high - strength concrete.". *Journal of Composites for Construction*, 18(4), 04013058. http://dx.doi.org/10.1061/(ASCE)CC.1943-5614.0000376

Tiwari P. K. and Singh V. K. (2023), "The Impact of Fiber Reinforcement on Fresh and Physical Properties with Durability of Recycled Coarse Aggregate Concrete: A Review." *Journal of Engineering Science & Technology Review*, 16(4), 85-93. http://dx.doi.org/10.25103/jestr.164.11

Poon C. S., Shui Z. H. and Lam L. (2004). "Effect of microstructure of ITZ on compressive Strenth of concrete prepared with recycled aggregate". *Construction and Building Materials,* 18(6), 461-468. https://doi.org/10.1016/j.conbuildmat.2004.03.005

Faraj R.H., Sherwani A. and Daraei A. (2019), "Mechanical, fracture and durability properties of self-compacting high strength concrete containing recycled polypropylene plastic particles",. *Journal of Building Engineering*, 25(1), 100808,. https://doi.org/10.1016/j.jobe.2019.100808

Yap S.P., Alengaram U. J. and Jumaat M. Z. (2013). "Enhancement of mechanical properties in polypropylene and nylon fiber reinforced oil palm shell concrete.". *Materials & Design,* 49(1), 1034-1041. http://dx.doi.org/10.1016/j.matdes.2013.02.070

Singh V. K. and Shukla A. (2021). "Structural Application of Concrete Made of Recycled Aggregate Sourced from Construction and Demolition Waste". *Proceedings of SECON'21, Springer International Publishing*, 171(1), 10.1007/978-3-030-80312-4_74.

Zhu W., (2020). "Permeation properties of self-compacting concrete. In: Siddique R (ed.) self-compacting concrete:Materials, properties and applications." . *Journal of Materials, Properties and Application Elsevier, 5(1),* 117-130. https://www.elsevier.com/books/self-compacting-concrete-materials-properties-and-applications/siddique/978-0-12-817369-5

Kang W. H., Ramesh R. B., Mirza O., Senaratne S., Tam V. and Wigg D. (2017). "Reliability Based Design of RC Beams With Recycled Aggregate and Steel Fibres". *Journal of Structures*, 11(1), 135–145. https://doi.org/10.1016/j.istruc.2017.05.002

Utepov Y., Akhmetov D.and Ilnur A. (2020). "Effect of fine fillers from industrial waste and various chemical additives on the placeability of self-compacting concrete".*Computers and Concrete*, 25(1), 59–65. https://doi.org/10.12989/cac.2020.25.1.059

Zhao Y., Zeng W. and Zhang H. (2017). "Properties of recycled aggregate concrete with different water control methods". *Construction and Building Materials,*152(1), 539-546. https://doi.org/10.1016/j.conbuildmat.2017.05.134

Bayashi Z. and Zeng J. (1993). " Properties of polypropylene fiber reinforced concrete." . *ACI Materials Journals, 90(6)*, 605–610. 10.14359/4439

Zhang P, Li Q., Chen Y., Shi Yan and Ling Y. (2019; 12). "Durability of steel fiber reinforced concrete containing SiO2 nano-particles." . *Materials (Basel) MDPI,* 12(13), 2184. http://dx.doi.org/10.3390/ma12132184

Zhou J, kang T. and Wang F. (2019). "Pore structure and strength of waste fiber recycled fiber". *Journal of Engineering Fibers and Fabrics,* 14(5), 1558925019874701. https://doi.org/10.1177/1558925019874701