

# Investigation of the Mechanical Properties of Self-Compacting Concrete (SCC) Reinforced with Hybrid Fibres

Shreenidhi Halu<sup>1</sup>, Dr. Brijbhushan S.<sup>2</sup>, Mr. Samrudh K.<sup>3</sup>

<sup>1</sup>Postgraduate Student, Department of Civil Engineering, Visvesvaraya Technological University, Center for PG Studies, Kalaburagi - 585105, Karnataka, India.

<sup>2</sup>Assistant Professor, Department of Civil Engineering, Visvesvaraya Technological University, Center for PG Studies, Kalaburagi - 585105, Karnataka, India.

<sup>3</sup>Research Scholar, Department of Civil Engineering, Visvesvaraya Technological University, Center for PG Studies, Kalaburagi - 585105, Karnataka, India.

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## ABSTRACT

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Self-Compacting Concrete is high-performance substance that flows with its own weight, eliminating the need for vibration and enabling easy placement in congested reinforcement zones. While SCC improves workability and surface finish, it often has lower tensile and flexural strength. This study shows the limitations by incorporating hybrid fibers steel fibers for strength and toughness, and polypropylene fibers for ductility and crack control into M30 grade SCC.

The mix was designed using OPC 53 grade cement, crushed sand as a replacement for river sand, 10 mm coarse aggregate, PCE-based superplasticizer (0.6%), and VMA (0.3%), following EFNARC guidelines. Hybrid fibers were added in varying proportions (0 – 1%). Fresh properties were evaluated by V-funnel, L-box, and slump flow tests. While hard properties of concrete were tested for compressive tests at 3, 7, 21, and 28 days. Final mix ratio was Cement: 312.9 kg/m<sup>3</sup>, Fine Aggregate: 926.5 kg/m<sup>3</sup>, Coarse Aggregate: 910.30 kg/m<sup>3</sup>, Water: 192 kg/m<sup>3</sup>, with a water-cement ratio of 0.43.

Results shows hybrid fibers enhanced strength and durability, with slump flow decreasing slightly as fiber content increased, and L-box ratios ranging from 0.82–0.98, indicating excellent passing ability. Peak mechanical performance was achieved at 0.75% fiber content, with a transition from brittle to ductile failure.

Overall, hybrid fiber-reinforced SCC demonstrated superior workability, strength, and toughness, making it a sustainable and efficient material for modern construction uses such as bridges, high-rise structures, and precast elements.

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**Keywords:** SCC, PCE, VMA, Workability, Hybrid fibre

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## I. INTRODUCTION

The term “concrete” originates from the Latin word “*concretus*”, meaning compact or condensed, which is the past participle of “*concrecere*”, derived from “*con*” (together) and “*crescere*” (to grow). Conventional concrete refers to standard concrete that is mixed, placed into molds or formwork, and then compacted to remove air voids. However, in high-rise construction or areas with dense reinforcement, placing and compacting concrete can be particularly difficult. If compaction is not done properly, it may result in voids, honeycombing, or weak spots, which can compromise the strength and durability of the structure. Traditional concrete lacks the natural flowability needed to spread and settle on its own. As a result, it relies heavily on manual labor and vibration equipment to achieve proper consolidation, which can be time-consuming, labor-intensive, and prone to human error.

To overcome these issues, SCC offers a promising alternative. This kind of concrete flows due to its own weight and get compacted, easily filling all areas of the mold even those with dense reinforcement while minimizing problems like segregation and bleeding.

Another concern in concrete production is the scarcity of river sand, a key ingredient. As demand increases, river sand supplies are being depleted, leading to environmental concerns. It's important for all of us to seek sustainable solutions. To build up the overall performance of concrete, researchers have explored the substitution of fibers. Fibers help improve resistance to cracking and enhance both strength and toughness. This has increased the growing interest in using both natural and synthetic fibers as reinforcement in concrete.

Among structural elements, beams and columns receive particular attention in research. Columns, which carry loads from horizontal members and transfer them to foundation, play a critical role in stability. The dimension of a column depends on loads it bears and materials strength that is being used.

### 1.1 Self-Compacting Concrete:

Self-Compacting Concrete (SCC), developed by Japanese scientists in the 1980s, was a game-changer for concrete, particularly for tall buildings. By minimizing flaws and guaranteeing top-notch finishing, SCC simplified and expedited the construction process. One distinguishing feature of SCC is its capacity to flow and condense without the assistance of external vibration. This allows the concrete to effortlessly fill crevices between tightly packed reinforcement bars, a task that is typically difficult for traditional concrete. Rapid global adoption and widespread acclaim have propelled SCC to the forefront of contemporary building technology since its inception. With SCC, there is no need for vibration, which results in safer and calmer work environments, quicker construction, and less human labour required compared to standard concrete by vibrating.

Self-Compacting Concrete (SCC) is an advanced variety of concrete that can self-compact without the assistance of vibratory machinery. Without material segregation or bleeding and maintaining homogeneity, SCC effortlessly fills complex molds and closely spaced reinforcing zones. Thus, its inherent weight causes it to condense itself naturally, without the need for any other assistance.

SCC's self-compaction makes it a noteworthy concrete technology innovation that has grown rapidly in recent decades. Benefits are numerous and significant. SCC speeds up building, smooths surfaces, and minimizes noise pollution by eliminating vibration equipment. The technology also allows thinner concrete portions without compromising strength or longevity, making it efficient and attractive. SCC's performance improves long-term durability and mechanical strength, which is important in infrastructure and architecture. The building and civil engineering sectors are interested in these benefits, boosting research and development. SCC's attractiveness has increased due to sustainability efforts. Researchers and engineers are adding quarry dust, fly ash, and other recyclable elements to SCC mixes. This improves concrete's environmental impact and minimizes natural raw material use. SCC also saves construction site energy by not requiring electrical equipment for vibration during placement. SCC's efficiency, sustainability, and superior performance attract civil engineers, software developers, and data scientists who use revolutionary programming and analysis tools to simulate, model, and optimize SCC behaviour.

Self-Compacting Concrete (SCC) is the best concrete innovation. Its capacity to compact by weight without vibration improves concrete quality. Furthermore, it considerably reduces building labour. Compression-free placement reduces placement costs, building time, and productivity. As time passes, SCC is used in more applications. Thus, Mechanical Properties of M30 Self-Compacting Concrete were investigated using crushed sand as a certified river sand substitute and hybrid fiber as reinforcement. Concrete mechanical qualities, particularly compressive strength, are examined here.

In the last 20 years, the construction industry has placed a strong focus on improving productivity and creating better working conditions. Concrete, once a basic mix of cement, water and aggregates, has evolved into a highly engineered material. It is now tailored to meet specific construction demands using a variety of new components.

## II. LITERATURE SURVEY

Pathan *et al.* (2022) utilized predictive modelling to assess the strength of SCC mixes incorporating steel and polypropylene fibers. In contrast, Sharma *et al.* (2022) indicated that the composition of SCC mixes and the conditions of curing had a significant impact on shrinkage and pavement strength. De Souza *et al.* (2022) demonstrated the efficacy of cellulose-based additives in enhancing dispersion and bonding within cement composites. Donmez *et al.* (2023) demonstrated that multi-blended binders in sustainable hybrid fiber-reinforced self-compacting concrete (SCC) improved both fresh and hardened properties. Son *et al.* (2023) integrated graphene oxide, carbon nanotubes, and nano silica into hybrid aqueous solutions, demonstrating significant enhancements in mechanical performance. Chen *et al.* (2023) examined the rheological properties of ultrahigh-performance concrete through wet-mix spraying, demonstrating enhanced workability and mechanical performance. Maneeth *et al.* (2024) studied the induction of steel fibres and polypropylene fibres with an

variation from 0., 1, 1.5, 2% by weight of cement in fibre reinforced self-compacting concrete. De Alencar Monteiro *et al.* (2023) examined the fatigue behaviour of steel fiber reinforced concrete, demonstrating that the degradation of the fiber–matrix interface significantly affects long-term durability.

Lerch *et al.* (2018) examined the impact of mixing methods on macro-synthetic fiber-reinforced concrete, concluding that appropriate mixing improved fiber distribution and overall structural performance. Thomas *et al.* (2016) examine the integration of industrial by-products, including pond ash, quarry dust, and recycled aggregates, into concrete. Their research indicates that these materials decrease the environmental impact of waste disposal while enhancing the mechanical and durability properties of concrete mixes when applied in regulated proportions. The combination of sustainability and performance improvement makes industrial by-products valuable components in green concrete technology.

Yoo and Banthia (2016) investigate the impact of hybrid fibre reinforcement, specifically the integration of steel and polypropylene fibres. Their findings indicate that hybridization yields synergistic advantages, improving both tensile strength and durability beyond the capabilities of individual fibers. The study demonstrates that steel fibres enhance load-bearing capacity and post-cracking resistance, whereas polypropylene fibres aid in shrinkage control and toughness, collectively forming a balanced fibre system.

Ozbakkaloglu (2015) examines the role of steel fibres in concrete, reporting that their inclusion significantly improves crack resistance, ductility, and post-cracking behaviour. The research indicates that steel fibres diminish brittleness and enhance energy absorption capacity, thereby rendering fibre-reinforced concrete more appropriate for structural applications that necessitate toughness and durability over time.

### III. PROBLEM STATEMENT AND OBJECTIVES

#### 3.1 Problem Statement

Because of its capacity to flow and compact under its own weight, self-compacting concrete (SCC) is frequently employed in contemporary construction. This property makes it perfect for intricate constructions and crowded reinforcement regions. But in its hardened condition, SCC frequently has drawbacks such decreased toughness, lower tensile strength, and vulnerability to microcracking, which over time can cause structural degradation.

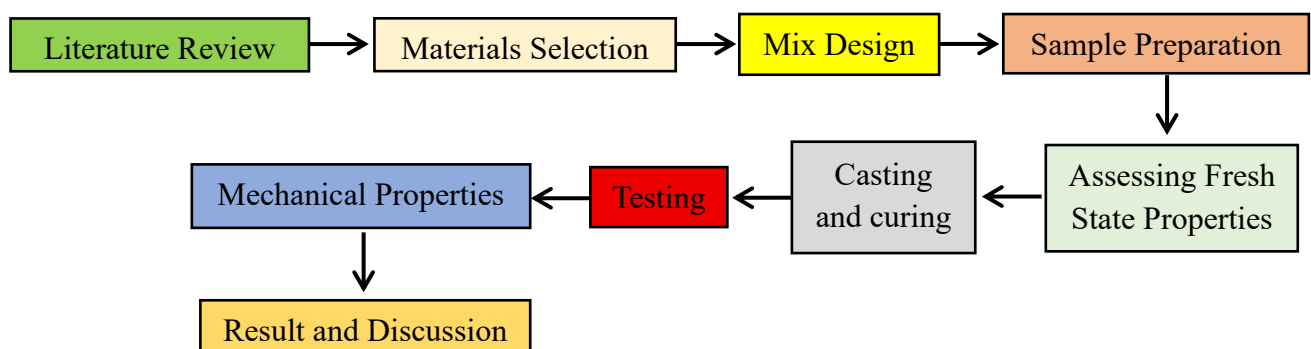
Fiber incorporation has been investigated as a potential remedy to address these issues. While polypropylene fibers aid in reducing plastic shrinkage and enhancing ductility, steel fibers improve compressive strength and toughness. They may be able to increase durability and strength when mixed as hybrid fibers. However, the addition of fibers may affect the fresh properties of SCC, such as flowability and passing ability, and the optimal dosage for achieving the best balance between workability and mechanical performance is not well established.

#### 3.2 Objectives

1. To investigate fresh properties of SCC.
2. To evaluate influence of Hybrid Fibres on Mechanical properties.
3. Comparing performance analysis of SCC with Hybrid Fibres.

### IV. METHODOLOGY AND MATERIALS

#### 4.1 Methodology



## 4.2 Chemical Admixture

The most significant admixtures employed in SCC are superplasticizers (high-range water reducers), which enable a water reduction of over 20% while preserving workability. Superplasticizers are essential for attaining the high workability necessary for SCC while preserving its structural integrity. When the powder content within the mixture is comparatively minimal, a Viscosity Modifying Agent (VMA) is frequently incorporated. VMA assists in regulating segregation and bleeding by enhancing the cohesion of the mixture. Together, these admixtures improve the homogeneity of SCC, assuring consistent distribution of materials and minimizing the risk of segregation, thereby enhancing both the fresh and hardened properties of the concrete.

### 4.2.1 Super Plasticizer:

Polycarboxylate Ether (PCE) is a next-generation high-performance admixture widely used in SCC to enhance its properties. It functions as a high-range water reducer or superplasticizer, designed to significantly improve workability and flowability while maintaining strength.

PCE consists of a carboxylic acid-based aqueous copolymer, which delivers high efficiency even at low dosages and is easy to blend into the concrete mix. This admixture provides excellent control over rheological properties, ensuring better performance of the cement paste and overall mix stability.

When added to concrete, PCE effectively reduces bleeding and segregation, while allowing up to a 30% reduction in water content without compromising the concrete's workability. Additionally, it helps delay the setting time, offering more flexibility during placement and finishing operations. In this study, PCE is used at a dosage of 0.6%, ensuring optimal flowability, uniformity, and strength development in the SCC mix.



**Figure No. 1:** *Polycarboxylate Ether (PCE) used in present investigation*

### 4.2.2 Viscosity Modifying Agent (VMA):

The primary purpose of a Viscosity Modifying Admixture (VMA) is to enhance the specific characteristics of fresh concrete, particularly its plastic viscosity. By increasing the plastic viscosity, VMA improves the cohesiveness of the mix, reducing the risk of segregation and bleeding, which is especially important for SCC applications.

When VMA is added to the concrete mix, it results in a moderate increase in plastic viscosity and a slight rise in the yield point. While plastic viscosity plays a crucial role in maintaining stability and flow, another key rheological property to consider is the yield point, which determines the stress required to initiate flow.

It is important to note that VMA does not significantly alter the yield point on its own. To adjust the yield point, plasticizers or superplasticizers are incorporated alongside VMA to achieve the desired balance between flowability and stability. In this project, VMA was used at a dosage of 0.3%, ensuring improved stability and uniformity of the SCC mix while maintaining proper workability.



**Figure No. 2:** *Viscosity Modifying Agent (VMA) used in present investigation*

### 4.3 Steel Fibre

In this study steel fibres were used which have excellent mechanical properties. Due to uniform distribution of fibres and high strength, the stresses can be dispersed, and propagation of crack can be effectively controlled.



**Figure No. 3:** *Micro Steel Fibre was used in present investigation*

**Table No. 1:** *Mechanical Features of Steel Fibre*

| Sl. No. | Materials                          | Steel Fibre  |
|---------|------------------------------------|--------------|
| 1       | Length (mm)                        | 13           |
| 2       | Diameter (mm)                      | 0.22 - 0.3   |
| 3       | Aspect ratio                       | 20-30        |
| 4       | Tensile Strength (m <sup>2</sup> ) | 2000         |
| 5       | Melting Point (°C)                 | 1500         |
| 6       | Appearance                         | Brass Coated |
| 7       | Cross Section                      | Round        |

**Table No. 2:** *Physical properties of Polypropylene Fibre*

| Sl. No. | Parameters               | Specifications |
|---------|--------------------------|----------------|
| 1       | Materials                | Polypropylene  |
| 2       | Specific Gravity         | 0.91           |
| 3       | Melting Point (°C)       | 165            |
| 4       | Equivalent Diameter (mm) | 0.8            |
| 5       | Length (mm)              | 50             |
| 6       | Tensile Strength (MPa)   | >600           |
| 7       | Young's Modulus (GPa)    | >6             |

|    |                            |           |
|----|----------------------------|-----------|
| 8  | Aspect Ratio               | >45       |
| 9  | Acid and Alkali Resistance | Excellent |
| 10 | Water Absorption           | Nil       |
| 11 | Electrical Conductivity    | -         |

#### 4.4 Polypropylene Fibre:

Polypropylene fibers play a crucial role in modern construction, offering significant advantages when added to concrete. These fibers are engineered for enhancing the strength and durability of concrete surfaces, helping to prevent issues like premature cracking.

Is Made from 100% high-quality modified fibers, polypropylene fibers act as an effective alternative to traditional steel mesh reinforcement. Their main function is to minimize the risk of cracks caused by shrinkage in both concrete and mortar, ensuring a more stable and long-lasting structure.



Figure No. 4: Polypropylene Fibre from SP Concure Pvt. Ltd. was used

One of the key benefits of using polypropylene fibers is the reduction in construction time. They blend easily with concrete and mortar, making the mixing process straightforward and efficient. In addition, they improve performance of the final surface by preventing erosion, providing better impact resistance and helping the concrete withstand heavy use and changing environmental conditions.

#### V. EXPERIMENTAL INVESTIGATION

Table No. 3: Represents the present Mix Ratio utilized in the investigation

| Cement<br>(kg/m <sup>3</sup> ) | Fine<br>Aggregate<br>(kg/m <sup>3</sup> ) | Coarse<br>Aggregate<br>(kg/m <sup>3</sup> ) | Chemical<br>Admixture | Water |
|--------------------------------|-------------------------------------------|---------------------------------------------|-----------------------|-------|
| 312.90                         | 926.50                                    | 910.30                                      | 2.68                  | 192   |
| 1                              | 2.765                                     | 2.704                                       | 0.0086                | 0.614 |

Table No. 4: Materials Required in kg/m<sup>3</sup> of concrete

| Materials (kg/m <sup>3</sup> ) | Conventional<br>Concrete | Designed mix<br>(M-30) |
|--------------------------------|--------------------------|------------------------|
| Cement                         | 490                      | 312.9                  |
| Slag                           | -                        | 89.4                   |
| Fine Aggregate                 | 932                      | 926.5                  |
| Coarse Aggregate               | 880                      | 910.299                |
| Water                          | 161                      | 192                    |
| Superplasticizer<br>(0.6%)     | -                        | 1.8774                 |
| VMA (0.3%)                     | -                        | 0.9387                 |

## VI. TEST RESULTS AND DISCUSSIONS

### 5.1 Test on Fresh Properties

#### 5.1.1 Slump Flow Test:

The slump flow test, which gauges the concrete's capacity to flow horizontally free from outside vibration or blockage, is used to assess the filling ability of self-compacting concrete (SCC). In the test, concrete is poured into the slump cone, which is subsequently raised to let the mixture spread out. The flowability of the concrete is indicated by the average diameter of the produced circle.

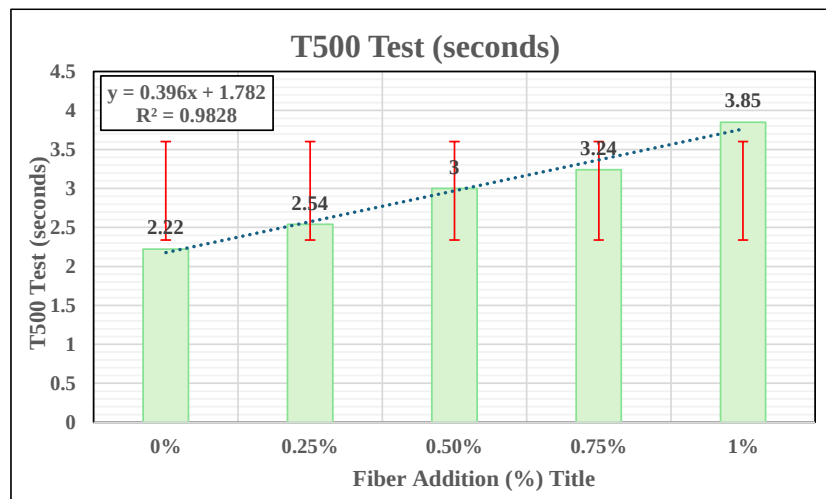


**Figure No. 5:** Flow Table test of Self compacting concrete

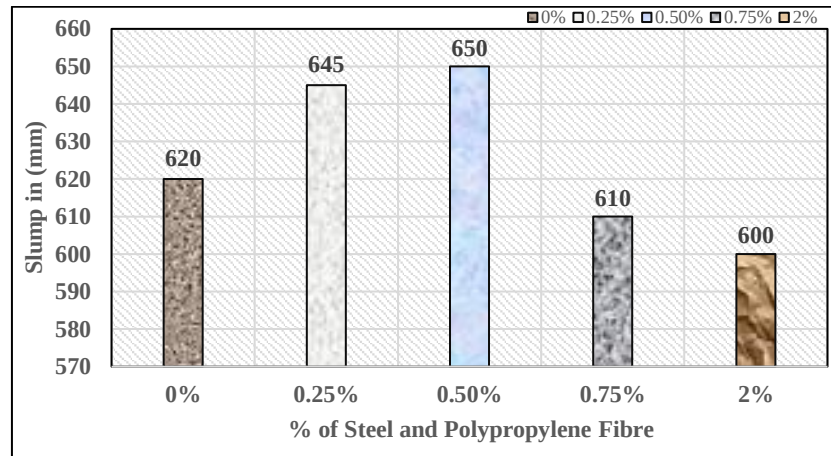
SCC typically exhibits a dense microstructure due to its higher powder content and reduced coarse aggregate proportion. The pressure resistance of SCC largely depends on its workability, as lower workability increases porosity within the concrete. Additionally, it has been observed that increasing fiber content tends to reduce the slump flow value, slightly affecting the free-flowing characteristic of the mix.

**Table No. 5:** Slump Flow Test Results

| Fiber Addition (%) | Slump Flow (mm) | T <sub>500</sub> Test (seconds) |
|--------------------|-----------------|---------------------------------|
| 0%                 | 620             | 2.22                            |
| 0.25%              | 644             | 2.54                            |
| 0.5%               | 650             | 3.00                            |
| 0.75%              | 609             | 3.24                            |
| 1%                 | 600             | 3.85                            |



**Graph No. 1:** T<sub>500</sub> Test Slump Flow of Various Percentage of Fibres



Graph No. 2: Slump Flow v/s Various Percentage of Fibres

### 5.1.2 L-Box Test

The L-box test is used to evaluate the passing ability of Self-Compacting Concrete (SCC), which indicates its capacity to flow through congested reinforcement without segregation. In this test, the vertical section of the L-box is first filled with concrete. Once ready, the gate is lifted, allowing the concrete to flow into the horizontal section.

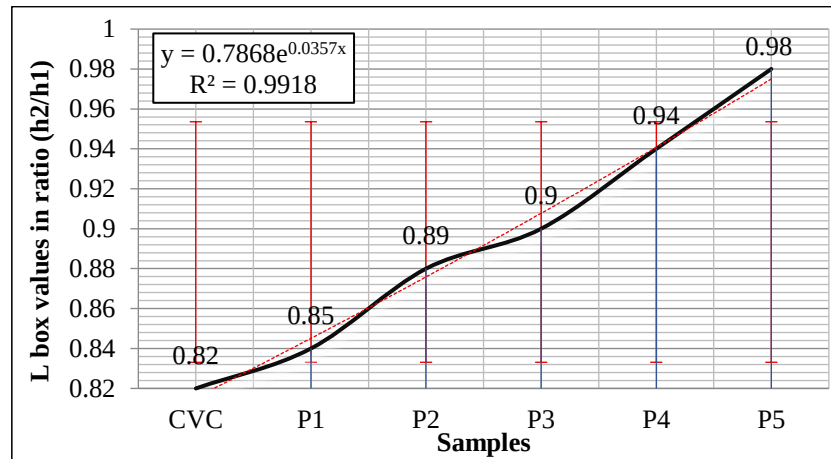
The height of concrete in the vertical section ( $h_2$ ) relative to the height in the horizontal section ( $h_1$ ) is measured at the end of the flow. This ratio ( $h_2/h_1$ ) reflects the concrete's passing ability. According to EFNARC guidelines, a ratio greater than 0.8 indicates that the SCC has excellent passing capability.



Figure No. 6: L Box test setup

Table No. 6: L-Box Test Results

| Sl. No. | Samples | L box values<br>in ratio<br>( $h_2/h_1$ ) |
|---------|---------|-------------------------------------------|
| 1       | CVC     | 0.82                                      |
| 2       | P1      | 0.85                                      |
| 3       | P2      | 0.89                                      |
| 4       | P3      | 0.9                                       |
| 5       | P4      | 0.94                                      |
| 6       | P5      | 0.98                                      |



Graph No. 3: L-Box values v/s Various % of Fibres used

### 5.1.3 V Funnel:

The V-funnel is used to examine the flowability of fresh concrete by measuring the time it takes to flow through a funnel. In this test, shorter flow times shows better flowability, while longer flow times may suggest poor workability or potential segregation.

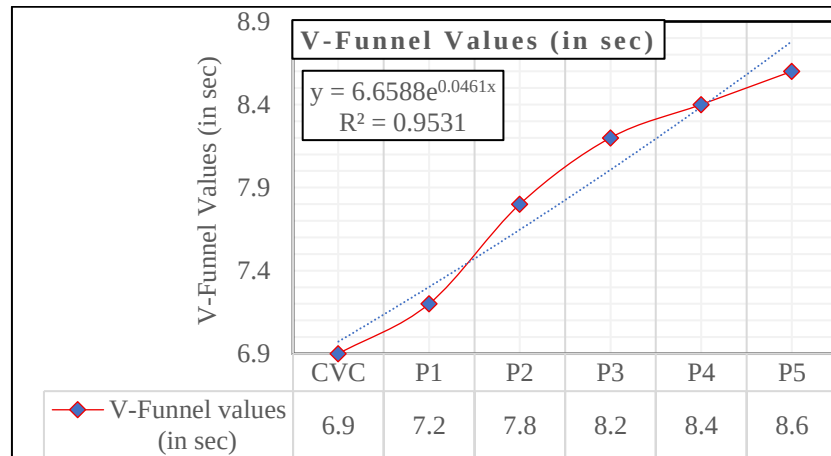
Segregation in the concrete mix leads to an interrupted or uneven flow, especially after about 5 minutes, resulting in high flow time. With respect to Khayat and Manai, for a concrete mix to qualify as SCC, the V-funnel flow time should be less than 6 seconds, ensuring adequate fluidity and uniformity.



Figure No. 7: Shows the flow of concrete from V-Funnel

Table No. 7: V-Funnel Test Results

| Sl. No | Samples | V-Funnel values (in sec) |
|--------|---------|--------------------------|
| 1      | CVC     | 6.9                      |
| 2      | P1      | 7.2                      |
| 3      | P2      | 7.8                      |
| 4      | P3      | 8.2                      |
| 5      | P4      | 8.4                      |
| 6      | P5      | 8.6                      |



Graph No. 4: Results of V-Funnel Test

## 5.2 Tests on Hardened Specifications of SCC

SCC properties was mechanically determined using performing testing compression, flexural testing and fractured tensile tests for hardened SCC concrete.

### 5.2.1 Compressive Strength:

Compressive strength is the ability of a material or structure to withstand loads applied to its surface without cracking or excessive deformation. Under compression, a material's size decreases, while under tension, it elongates.

After the respective curing periods, the cubes were tested using a compression testing machine with a capacity of 1000 kN, following IS 516–1959 guidelines. The compressive strength ( $f_{ck}$ ) was calculated using the formula:

$$f_{ck} = \frac{P}{A}$$

Where:

- P = Ultimate load in compression (kN)
- A = Cross-sectional area of the specimen (mm<sup>2</sup>)

The average compressive strength was determined from the specimens tested at each curing age to evaluate the performance of SCC with varying fiber contents.



Figure No. 8: Compressive Strength Testing Machine



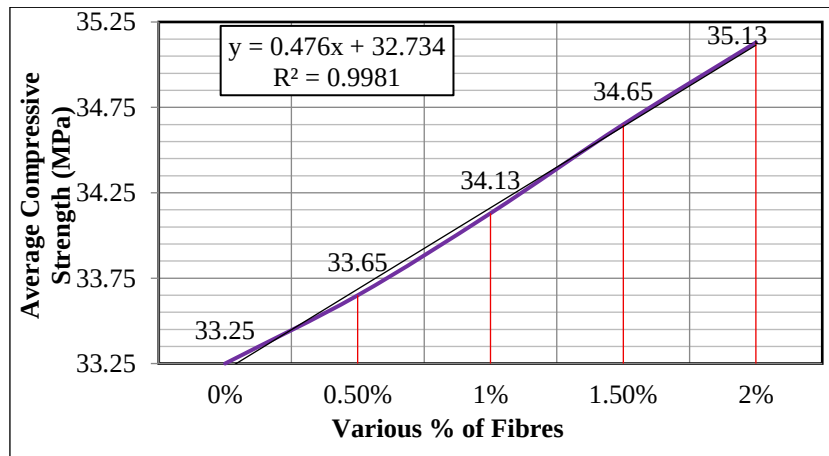
Figure No. 9: Compressive Testing of Cubes

After curing, cube specimens are used to measure the concrete's compression strength. The findings of measuring the specimens' compressive strength after 3, 7, 21, and 28 days of curing are displayed in the table below.

a) For Designed Concrete of M 30 Grade

Table No.8: Compression Test Output at 21 days curing

| Sample No.     | Silica Fume, Slag, Various % of Steel and Polypropylene | Concrete Compressive Strength (N/mm <sup>2</sup> ) |        | Average Compressive Strength (N/mm <sup>2</sup> ) |
|----------------|---------------------------------------------------------|----------------------------------------------------|--------|---------------------------------------------------|
|                |                                                         | Cube 1                                             | Cube 2 |                                                   |
| P <sub>1</sub> | 0 %                                                     | 33.10                                              | 33.40  | 33.25                                             |
| P <sub>2</sub> | 0.5 %                                                   | 33.50                                              | 33.80  | 33.65                                             |
| P <sub>3</sub> | 1 %                                                     | 34.00                                              | 34.25  | 34.13                                             |
| P <sub>4</sub> | 1.5 %                                                   | 34.50                                              | 34.80  | 34.65                                             |
| P <sub>5</sub> | 2 %                                                     | 35.00                                              | 35.25  | 35.13                                             |

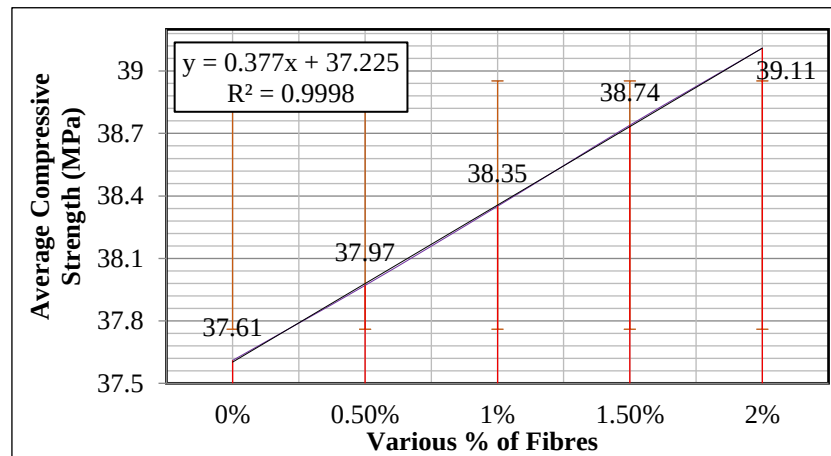


Graph No. 5: Average Compressive Strength of design mixes with variation of fibers at 21 days

Table No. 9: Compression Test Output at 28 days curing

| Sample No.     | Silica Fume, Slag, Various % of Steel and Polypropylene | Concrete Compressive Strength (N/mm <sup>2</sup> ) |        | Average Compressive Strength (N/mm <sup>2</sup> ) |
|----------------|---------------------------------------------------------|----------------------------------------------------|--------|---------------------------------------------------|
|                |                                                         | Cube 1                                             | Cube 2 |                                                   |
| P <sub>1</sub> | 0 %                                                     | 37.485                                             | 37.73  | 37.61                                             |
| P <sub>2</sub> | 0.5 %                                                   | 37.867                                             | 38.077 | 37.97                                             |
| P <sub>3</sub> | 1 %                                                     | 38.25                                              | 38.441 | 38.35                                             |
| P <sub>4</sub> | 1.5 %                                                   | 38.632                                             | 38.842 | 38.74                                             |

|       |     |        |        |       |
|-------|-----|--------|--------|-------|
| $P_5$ | 2 % | 39.015 | 39.206 | 39.11 |
|-------|-----|--------|--------|-------|



**Graph No. 6:** Average Compressive Strength at 28 days

## CONCLUSIONS

1. The fresh property tests, including Slump Flow, L-Box, and V-Funnel, confirmed that SCC achieved good flowability and passing ability as per EFNARC guidelines. This shows that the designed mix was suitable for self-compacting applications.
2. The Slump Flow test results indicated that the flowability of SCC decreased slightly with an increase in hybrid fiber content. The reduction was due to obstruction caused by steel and polypropylene fibers in the mix.
3. The optimum slump value was observed at 0.5% fiber content, beyond which the flowability started to decrease significantly, affecting workability.
4. The L-Box test showed that the ratio of  $h_2/h_1$  was greater than 0.8 for all fiber percentages, indicating excellent passing ability even at higher fiber dosages.
5. The V-Funnel test demonstrated that the flow time remained within acceptable limits up to 0.5% fiber content. At higher fiber percentages, the flow time increased, indicating a slight risk of segregation.
6. The compressive strength of SCC with hybrid fibers was consistently higher than that of conventional concrete at all curing periods of 3, 7, 21, and 28 days.
7. The maximum compressive strength of 39.11 N/mm<sup>2</sup> was recorded at 28 days for SCC containing 2% hybrid fibers, which was significantly higher compared to the control mix.
8. Early strength development was also improved in the hybrid fiber mixes, with noticeable strength gain at 3 and 7 days, showing the positive effect of fibers on early hydration.
9. The optimum hybrid fiber content was determined to be 1.5%, providing the best balance between strength enhancement and workability without major reduction in flowability.
10. The combination of steel and polypropylene fibers effectively controlled micro-cracks and improved durability, making SCC with hybrid fibers a reliable choice for heavily reinforced structures, precast elements, and high-performance concrete applications.

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