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Technical Notes

The Effect of Adding Pc Strand Waste to K-350 Quality Concrete on the Compressive Strength, Flexural Strength, and Abrasion of Concrete for Rigid Pavement Applications

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ABSTRACT: Steel Fiber Reinforced Concrete (SFRC) enhances the mechanical properties of concrete, such as tensile strength, compressive strength, and abrasion resistance. At PT Waskita Beton Precast Plant Karawang, waste generated from prestressed strands (PC strands) has raised environmental concerns. This study investigates the effect of incorporating PC strand waste on the mechanical properties of concrete. Tests were conducted on concrete beams (60 × 15 × 15 cm) for flexural strength, cylinders (30 × 15 cm) for compressive strength, and smaller cylinders (10 × 6.67 cm) for abrasion resistance, with variations in PC strand content evaluated at 7, 14, and 28 days. The results show that the addition of 1.5% PC strand significantly improved the concrete's properties. Compressive strength increased by 13.15% (4.13 MPa), while flexural strength rose by 57.84% (2.62 MPa) with 2.0% PC strand. The abrasion test showed the lowest mass loss in concrete without PC strand. The optimal mixture, containing 1.5% PC strand, achieved a compressive strength of 34.64 MPa, a flexural strength of 6.58 MPa, and a mass loss of 1.77 grams. This type of concrete is suitable for use in rigid pavements and bridge structures.

Keywords: PC Strand, Compressive Strength, Flexural Tensile Strength, Abrasion, Rigid Pavement.

1. Introduction

Despite significant advances in structural engineering technology in Indonesia, concrete remains the main material for infrastructure such as high-rise buildings, highways, and dams due to its low cost, high compressive strength, and ease of molding. However, it has drawbacks—brittleness, low tensile strength, and limited ductility—that can cause early cracking, especially in rigid pavements. In response to growing needs, technological advances, and sustainability awareness, various studies have focused on improving concrete quality using industrial waste additives such as fly ash, iron powder, and steel fibers to enhance performance while reducing environmental impact.

Fiber addition—especially steel fibers—has been shown to significantly improve mechanical properties. Moustafa et al. (2021) found that combining 0.60% steel fiber (SF) and 0.40% polypropylene fiber (PPF) increased compressive strength by 13.23%, tensile strength by 67.79%, and permeability by 325.54%, though abrasion also rose. Hosseinkhah et al. (2023) reported that tin waste fibers improved compressive, tensile, and flexural strengths by up to 40%, 15%, and 93%, respectively. Similarly, waste carbon fibers enhanced strength and durability by improving the aggregate–matrix bond (Abreu et al., 2020). Nurhidayatullah (2019) showed that cold-rolled corrugated steel fibers increased flexural strength up to an optimum dosage (1% for compressive, 6% for flexural strength). Other industrial wastes—glass, plastic, and ceramic fibers—also improved mechanical performance and reduced carbon emissions (Tahwia et al., 2024). Although waste fibers reduce workability, they enhance resistance to abrasion and cracking (Anwar et al., 2022) and improve durability (Putra et al., 2020).

Steel Fiber Reinforced Concrete (SFRC) integrates steel fibers to enhance tensile strength. While previous studies focused on commercial or metallic fiber waste, research on PC strand waste as reinforcing fibers—especially for rigid pavement—is still limited. Its mechanical and abrasion properties have not been fully explored.

Aligned with recent research trends, several contemporary studies indicate that the addition of polymer fibers and industrial waste materials not only enhances compressive, tensile, and flexural strengths but also improves durability parameters such as carbonation depth, water absorption, and resistance to aggressive environments. For example, Self-Compacted High-Performance Concrete (SCHPC) incorporating recycled coarse aggregates and polypropylene fibers at 0.2–0.6% demonstrated increased compressive and split tensile strength up to an optimum of 0.4%, along with a 16–17% reduction in carbonation depth compared with the control mix (Tiwari and Singh., 2025). These findings highlight the substantial potential of unconventional waste fibers to improve the mechanical and durability properties of concrete, making them highly relevant for application in both structural concrete and pavement systems.

Based on these research gaps, the present study investigates the effect of adding PC strand waste to K-350 concrete on its compressive strength, flexural tensile strength, and abrasion resistance. The tests were conducted in accordance with SNI 1974:2011 (compressive strength), SNI 4431:2011 (flexural strength), and ASTM C944 (abrasion). The results are expected to provide scientific evidence regarding the feasibility of utilizing PC strand waste as an alternative reinforcing material for rigid pavement and bridge structures, while supporting sustainable waste utilization.

2. Material and Methods

This study experimentally investigates the effect of adding PC strands on the workability and mechanical properties of K-350 concrete—specifically compressive strength, flexural tensile strength, and abrasion resistance—by comparing various percentages of PC strand addition to normal concrete. The modified mix, known as Steel Fiber Reinforced Concrete (SFRC), uses PC strands as reinforcing fibers. According to the ACI Committee 544 (1999), SFRC pavements can reduce thickness by up to 50% compared to conventional concrete.

Concrete was mixed using the standard procedure Kementerian Pekerjaan Umum dan Perumahan Rakyat (2024) with five mix variations: one control (0%) and four SFRC mixtures containing 0.5%, 1.0%, 1.5%, and 2.0% PC strands by volume. The optimal steel fiber content in medium- and high-strength concrete generally ranges from 1.5% to 2.0%. While metallic or synthetic fibers at optimal dosages (1–2%) can improve mechanical strength, excessive amounts may decrease workability and cause fiber agglomeration (Hung et.al., 2020).

2.1. Materials

The research used Type I Portland cement without special specifications (Taher et al., 2024); clean water free from oil and silt (Chusai et al., 2024); crushed stone and sand tested for specific gravity, water absorption, and gradation based on SNI 03-2834-2000; and PC strand as shown in Figure 1.

Fig 1. Pieces of PC Strand

Steel fiber distribution in fresh concrete followed standard mixing methods. Previous studies used steel fibers 60–70 mm long, 0.9–3 mm in diameter, with aspect ratios (l/d) of 23–65 (Taher et al., 2024). Fiber addition up to 1–2% can increase compressive strength by 25% and flexural strength by 20–32%, while excessive fiber (>2%) may decrease strength due to porosity and uneven distribution (Ulu et al., 2022). In this study, the PC strand used measured 70 mm in length and 3 mm in diameter, giving an aspect ratio of 23.33.

2.2. Methods

Following a literature review, the research was conducted at PT Waskita Beton Precast Plant, Karawang. The experimental procedure was organized into seven main steps, summarized as follows:

1. **Material and Equipment Preparation:** All necessary materials and equipment for sample preparation and testing were collected.
2. **PC Strand Cutting:** Waste PC strands were cut using a seated grinder according to predetermined aspect ratios to be used as fiber reinforcement.
3. **Mix Design and Composition:** Five concrete mix variations were prepared based on SNI 03-2834-2000, with fiber contents ranging from 0% to 2.0%. The SFRC 0% mix served as the control. Mix details are provided in Table 1.

Table 1. Mix Design

Mix	Cement (kg/m^3)	Coarse Agg. (kg/m^3)	Fine Agg. (kg/m^3)	w/c	Fibre (kg/m^3)
SFRC 0,0%	427	1031	687	0,48	0,00
SFRC 0,5%	427	1031	687	0,48	39,25
SFRC 1,0%	427	1031	687	0,48	78,50
SFRC 1,5%	427	1031	687	0,48	117,75
SFRC 2,0%	427	1031	687	0,48	157,00

4. **Specimen Preparation and Curing:** Test specimens were prepared using the five mix variations. Flexural strength specimens (60 × 15 × 15 cm beams) were tested at 7, 14, and 28 days, with a total of 45 specimens. Abrasion test specimens (cylinders measuring 10 × 6.67 cm) were tested at 28 days, using 15 specimens in total. All samples underwent standard curing prior to testing.
5. **Mechanical and Durability Testing:**
   - *Compressive strength* was tested according to SNI 1974:2011.
   - *Flexural strength* was assessed using a two-point loading setup, based on SNI 4431:2011.
   - *Abrasion resistance* was evaluated following ASTM C944, using a rotating cutter to simulate immediate abrasive effects
6. **Data Analysis:** All test results, including slump, compressive strength, flexural strength, and abrasion resistance, were analyzed. The relationships between slump and mechanical properties were also examined to determine the optimal fiber content.
7. **Conclusion Drawing:** The study concluded by interpreting the findings in relation to the research objectives and

identifying the optimal PC strand content to enhance concrete performance.

2.3. Research of Flow

This section outlines the phases of the research, which are illustrated in Figure 2 as a process flowchart.

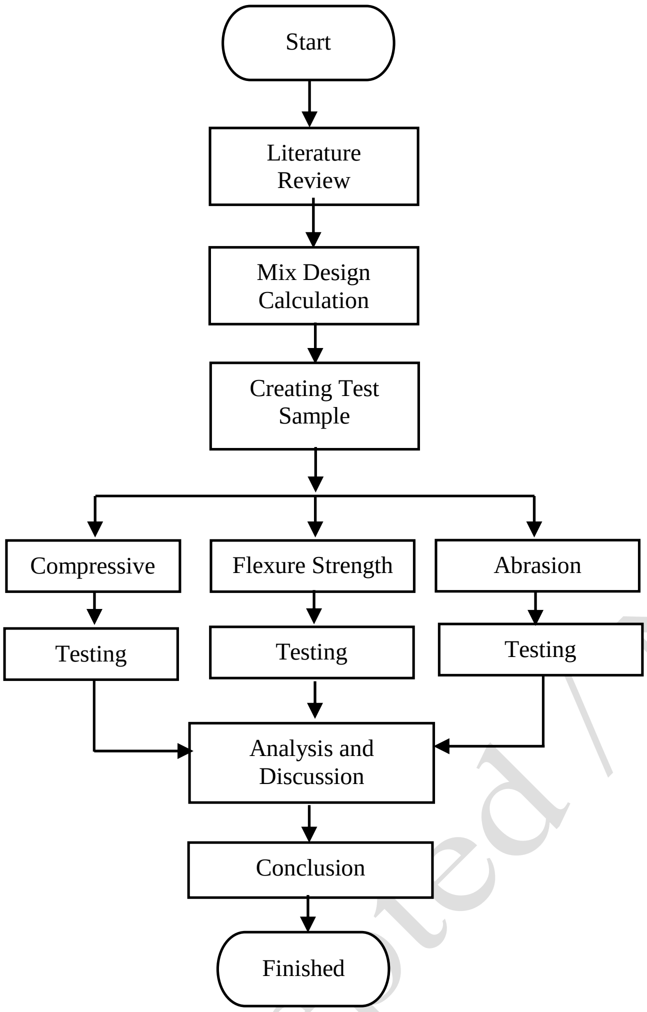


Fig 2. Research Flowchart

3. Results And Discussion

To determine the compressive strength, flexural tensile strength, and abrasion resistance of the concrete, data from testing and research were recorded, collected, and analyzed. The study was conducted on K-350 concrete with PC strand incorporated into the mix.

3.1. Slump Test

The slump test was conducted according to the SNI 1972:2008 standard. The consistency and workability of fresh concrete are measured by the concrete slump, which has a direct impact on how simple it is to place, compact, and polish the concrete. A mix is said to be more fluid if its slump value is higher, and stiffer if it is lower (Rahman et al., 2024). The strength, longevity, and appearance of the completed construction are all impacted by the proper concrete slump, which makes it crucial. The concrete mix will be workable and easy to handle with the right slump, making placement easier. The possibility of voids and air pockets in the hardened concrete is decreased by having the proper consistency, which enables effective compaction. This directly impacts the concrete strength and durability. Figure 3 presents the slump values for each concrete mix variation.

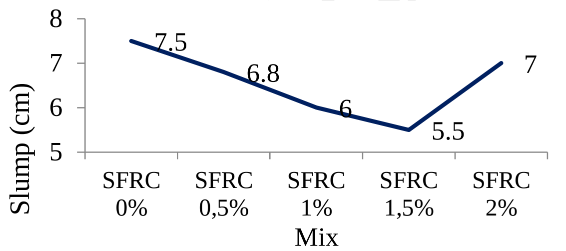
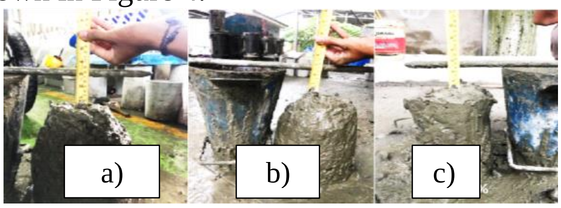


Fig 3. Slump Value

The slump values for each concrete mixture are presented in Figure 4 as a graph. According to the Peraturan Beton Bertulang Indonesia specifications, the slump value for K-350 concrete used in reinforced concrete road applications should be between 50 and 75 mm. The results for the SFRC mixes indicate that the slump value decreases as the percentage of added PC strand increases (Moustafa et al., 2021). This reduction occurs because the PC strand restricts the flowability of fresh concrete and increases its resistance to deformation. However, there is a limit to this trend. At 2% PC strand content, the slump value increases due to the large geometry of the PC strand compared to typical steel fibers, causing the fresh concrete to flow and collapse. The concrete slump test setup is shown in Figure 4.



d) e)

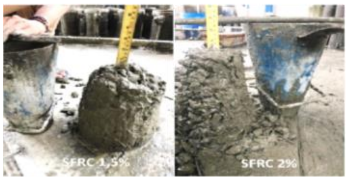


Fig 4. Slump test: a) SFRC 0%; b) SFRC 0,5%; c) SFRC 1%; d) SFRC 1,5%; and e) SFRC 2%.

3.2. Compressive Strength

The compressive strength test followed SNI 1974:2011 using concrete under axial load. Results for five SFRC mixes (0–2% PC strand) at 7, 14, and 28 days (Figure 5) showed that 1.5% fiber content provided the best performance, achieving a 28-day strength of 34.64 MPa—13.15% higher than the control mix. Strength improvement is attributed to the fiber's restraining effect, which increases concrete density (Putra et al., 2020), while excessive fibers cause voids due to clumping, reducing compactness. SFRC also exhibited fewer and slower-forming cracks, indicating improved ductility.

In general, steel fibers enhance the compressive strength and ductility of concrete, with optimal results at 1–2% fiber content (Jang et al., 2023). Beyond 2–3%, agglomeration and increased porosity reduce strength and workability (Jian et al., 2021). Moreover, hooked-end and high–aspect ratio fibers provide superior strength and ductility compared to straight fibers. Overall, the 1.5% fiber dosage yielded the most balanced enhancement in strength, toughness, and crack resistance.

	SFRC 0%	SFRC 0,5%	SFRC 1%	SFRC 1,5%	SFRC 2%
7 days	22.11	17.01	20.84	25.71	20.73
14 days	27.52	24.62	27.80	33.46	26.37
28 days	30.61	27.13	32.48	34.64	31.055

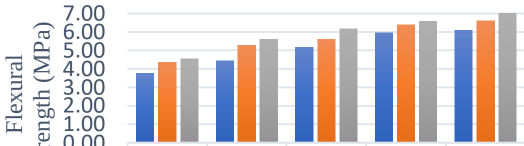
Fig 5. Compressive Strength

3.3. Flexural Strength

The flexural tensile strength test was conducted according to SNI 4431:2011 using a two-point loading method, as illustrated in Figure 6. This method applies a perpendicular force to the concrete specimen until failure occurs, enabling the assessment of its flexural behavior. The flexural tensile strength results of SFRC concrete with five different fiber contents are shown in Figure 7 for 7, 14, and 28 days.

- At 7 days, flexural strength increased by 17.65%, 36.47%, 57.65%, and 61.18% for fiber contents of 0.5%, 1%, 1.5%, and 2%.
- At 14 days, the increases were 21.43%, 28.57%, 46.94%, and 52.04%.
- At 28 days, improvements reached 23.53%, 36.27%, 45.10%, and 57.84% compared to the control mix.

Concrete with added PC strand content demonstrates that increasing the proportion of PC strands enhances flexural strength (Kos et al., 2022). Based on the flexural tensile strength test results, the highest strength was observed in the SFRC mix with 2% PC strand content at 28 days, reaching 7.16 MPa—an increase of 57.84% compared to the control concrete without fibers.



	SFRC 0%	SFRC 0,5%	SFRC 1%	SFRC 1,5%	SFRC 2%
7 Days	3.78	4.44	5.16	5.96	6.09
14 Days	4.36	5.29	5.60	6.40	6.62
28 Days	4.53	5.60	6.18	6.58	7.16

Fig 6. Flexural Strength

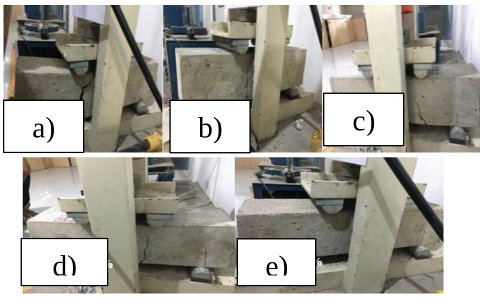


Fig 7. Flexure strength test: a) SFRC 0%; b) SFRC 0,5%; c) SFRC 1%; d) SFRC 1,5%; and e) SFRC 2%.

3.4. Abrasion

The abrasion test on steel fiber reinforced concrete (SFRC) aims to evaluate the surface wear resistance of concrete, particularly in applications such as industrial floors, pavements, and hydraulic structures. The test was conducted in accordance with ASTM C944, consisting of three test cycles, each lasting two minutes. The abrasion value was determined by calculating the difference between the specimen's initial and final weights after each cycle, as shown in Figure 8 and Table II for 28-day concrete specimens.

The results indicated that the greatest mass loss occurred in the SFRC mix with 0.5% PC strand, losing 2.37 grams (0.19%), followed by the SFRC mixes with 1% and 2% PC strand, each losing 1.83 grams, and the SFRC 1.5% PC strand mix losing 1.77 grams (0.16%). The control mix (0% PC strand) showed the lowest mass loss, with only 1.20 grams (0.11%), indicating the highest abrasion resistance.

The addition of steel fibers generally enhances the abrasion resistance of concrete by preventing microcrack propagation caused by frictional forces, although this effect tends to diminish beyond a certain dosage (Fan et al., 2022). Fiber type and geometry also play a role; hook-ended fibers and those with greater length provide better abrasion resistance than straight or shorter fibers (Phan and Nguyen., 2024).

Abrasion resistance is also influenced by compressive strength, as higher compressive strength consistently results in improved abrasion performance (Kaplan et al., 2021). A lower water–cement ratio (w/c) further enhances resistance by producing a denser concrete matrix (Hasnat and Nader, 2021). In general, the good abrasion resistance of SFRC is associated with the larger size and diameter of PC strands compared to conventional steel fibers (Moustafa et al., 2021) and tends to increase with higher compressive strength (Cho and Nam, 2022).

Table 2. Abrasion Test Result

Mix	Initial (g)	Period I (g)	Period II (g)	Period III (g)	Abrs (g)
SFRC 0%	1089.57	1089.30	1089.00	1088.37	1.20
SFRC 0.5%	1233.33	1232.27	1231.77	1230.97	2.37
SFRC 1%	1163.63	1163.20	1162.27	1161.80	1.83
SFRC 1.5%	1133.77	1133.27	1132.47	1132.00	1.77

Based on the results of the abrasion test, the SFRC 0% concrete exhibited the least amount of wear, with a mass loss of only 1.20 grams.

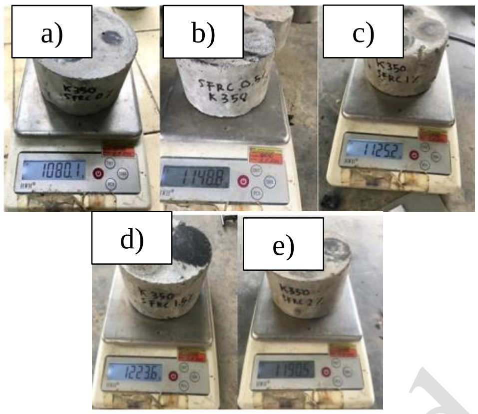


Fig 8. Abrasion; a) SFRC 0%; b) SFRC 0,5%; c) SFRC 1%; d) SFRC 1,5%; and e) SFRC 2%.

3.5. Compressive Strength Against Slump

Figure 9 illustrates the relationship between compressive strength and slump for concrete at 28 days of age.

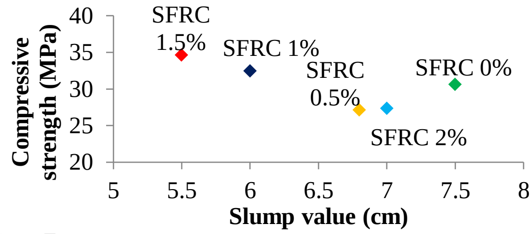


Fig 9. Show the correlation between slump value and compressive strength

It was observed that as the slump value decreased, the compressive strength generally increased, reaching its peak at SFRC 1.5%. Beyond this point, the compressive strength declined at SFRC 2%. The addition of PC strand restricts the flow of fresh concrete and increases its resistance to deformation, resulting in lower slump values (Moustafa et al., 2021). However, at 2% PC strand content, the large geometry of the strands compared to typical steel fibers led to excessive clumping and reduced workability, causing the mix to collapse. Consequently, SFRC 1.5% demonstrated the optimal performance, with the highest compressive strength of 34.64 MPa and a slump value of 5.5 cm.

Concrete's compressive strength and slump value are correlated; the higher the slump value, the lower the concrete's compressive strength likely to be. This is due to the fact that the more water in the concrete mixture, the more pore space there will be in the concrete, which will lower the concrete's strength. Conversely, a low slump number indicates that the concrete is denser and contains fewer voids, increasing its compressive strength. But an excessively low slump value can also be problematic because it might make it hard to work the concrete and possibly make it harder to get the ideal density. The increase in slump value due to the addition of water (higher water–cement ratio) causes a proportional decrease in compressive strength. This occurs because the added water creates more pores, thereby reducing the concrete's strength (Salain, 2021).

3.6. Strength of Flexural Tension Against Slump

Figure 10 illustrates the relationship between flexural tensile strength and slump at 28 days of age.

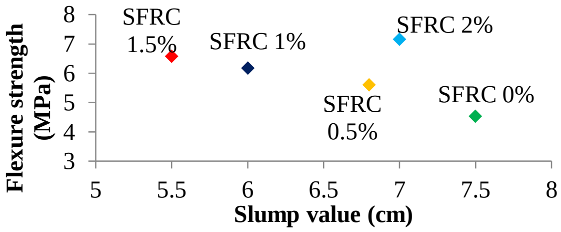


Fig 10. Show the correlation between slump value and flexural tensile strength

Flexural tensile strength increased with each variation in PC strand content and showed an inverse correlation with slump value, which decreased as PC strand content increased—except at 2% PC strand content, where the slump value rose. The optimal flexural tensile strength was achieved at 1.5% PC strand content, with a value of 6.58 MPa and a corresponding slump of 5.5 cm.

Concrete with a higher slump (more workable, lower viscosity) typically has a lower flexural strength, which means it can withstand bending forces less well. The concrete's structure is weakened by a higher slump, which frequently denotes a higher water-to-cement ratio. Conversely, since it indicates a more dense and well-compacted concrete mix, lesser slump (stiffer, higher viscosity) can indicate stronger flexural strength. The relationship between slump and flexural strength in concrete with fibers shows that adding fibers to concrete can reduce the slump value so that resistance to flexural tensile strength increases (Souvik et al., 2020). However, an excessively high fiber content (>1.5–2%) can significantly reduce workability and lead to a decrease in strength due to fiber agglomeration (Malah et al., 2024).

3.7. Strength of Compression Against Flexural Tensile Strength

Figure 11 shows the correlation between compressive strength and flexural strength at 28 days of age.

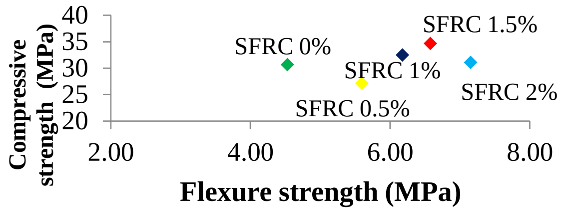


Fig 11. The connection between compressive strength and flexural tensile strength

The flexural tensile strength consistently increases up to SFRC 2%, while the compressive strength shows an increasing trend up to SFRC 1.5% before declining. Based on these results, SFRC 1.5% concrete—with a compressive strength of 34.64 MPa and a flexural tensile strength of 6.58 MPa—is considered the most optimal mix.

4. Conclusion

According to the research and analysis conducted, SFRC concrete with 1.5% strand content exhibited the highest compressive strength at 28 days, reaching 34.64 MPa. Compared to normal concrete, the addition of 1.5% SFRC improved compressive strength by 4.03 MPa (13.16%), whereas a 0.5% SFRC content resulted in a significant reduction of 3.48 MPa (-11.38%) at the same age. Regarding flexural tensile strength, the highest value was observed in SFRC with 2% strand content, measuring 7.16 MPa at 28 days. In comparison to SFRC 0% (regular concrete), all SFRC variations (0.5%, 1%, 1.5%, and 2%) showed improvements in flexural strength, with SFRC 2% demonstrating an increase of 2.63 MPa (57.84%) over standard concrete at 28 days. The lowest concrete abrasion loss at 28 days was recorded in SFRC 0%, with a mass loss of 1.20 grams. Considering the relationships between compressive strength, flexural tensile strength, abrasion, and slump test results, the optimal steel strand content for concrete is 1.5% SFRC, which provides the highest compressive strength (34.64 MPa), a flexural tensile strength of 6.58 MPa, an abrasion loss of 1.77 grams, and a slump value of 5.5 cm.

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