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Research Article

Mechanical performance evaluation of conventional and pervious concrete reinforced with steel and nylon fibers

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ABSTRACT

Performance enhancement of concrete to meet modern infrastructure demands has become essential in the construction industry. This study presents an experimental investigation of the incorporation of steel and nylon fibers in conventional and pervious concrete to evaluate their mechanical strength and permeability behavior. Fibers were added to the mix at 0.25%, 0.50%, 0.75%, and 1.0% by weight of cement. The studied parameters were the compressive strength, split tensile strength, density, porosity, and permeability. The experimental results revealed that, with optimum dosage, both fibers affected the mechanical properties of conventional and pervious concrete. The tensile strength showed a remarkable increase (approximately 45% for steel fibers), primarily through crack-bridging mechanisms within the matrix. Higher dosages of steel fibers were more effective than lower contents. Nylon fibers at a low dosage (0.25%) provided optimum performance, whereas 0.75% content also showed a notable strength increase. The density of both concrete types demonstrated only marginal variation. The permeability of pervious concrete, however, exhibited a slight increase at low fiber content, followed by a decrease with further fiber addition, indicating a trade-off between strength and hydraulic functionality. A comparative analysis of both concrete types was also performed. The findings demonstrate that controlled incorporation of steel and nylon fibers enhances the load resistance of both types of concrete while an optimal dosage is required to maintain adequate permeability, thereby contributing to more durable and sustainable construction practices.

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1. Introduction

In the construction industry, concrete plays the role of a prime component on a global scale and has become one of the most consumed materials worldwide after water (Gagg 2014; Nouri et al. 2025; Xiao et al. 2025). It is used in the construction and development of infrastructures and urbanization due to its high compressive strength, durability, stiffness, and ease of production

(Kosmatka et al. 2008; Varshney et al. 2021). The strength of concrete depends on the properties and strength behavior of its constituent elements – cement, fine aggregate, coarse aggregate, and mixing water (Konitufe et al. 2023; Rashid and Mansur 2009). However, plain concrete has some inherent limitations such as very low tensile strength, approximately one-tenth of its compressive strength (Akinpelu et al. 2019; Badarloo et al. 2018; McCormac and Brown 2013); brittle failure

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behavior, strength degradation at higher temperature, and limited crack-resisting ability (McCormac and Brown 2013). In order to enhance these capacities, steel reinforcing bars are commonly used in concrete structures. These reinforcements can provide strength in the designed direction only, not ensuring uniform tensile and flexural strength in all directions. To overcome this, fiber reinforced concrete (FRC) has emerged as an effective strengthening approach to improve the mechanical properties of concrete through crack bridging and fracture resistance in all directions (Lee et al. 2022; Li et al. 2023; Urtekin and Çelik 2025). Various types of fibers have been incorporated into concrete to improve its strength and mechanical properties, each offering distinct reinforcement mechanism and performance characteristics (Anas et al. 2022; Khan and Abbas 2025).

Steel fibers have been widely reported for improving the mechanical strength of concrete, its ductility, and toughness, due to their inherent stiffness and high bond with the cement matrix (Amin et al. 2022; Faustmann et al. 2024; Sitorus et al. 2025). It also enhances the flexural and shear strength of concrete structural elements (Koo et al. 2023; Krassowska and Kosior-Kazberuk 2021). On the other hand, synthetic fibers such as polypropylene and nylon fibers contribute to improved ductility and crack resistance by controlling the microcrack formation during the early loading stages (Ali et al. 2022; Bheel et al. 2021; Tanash et al. 2025; Nandaraj and Mourougane 2026). The incorporation of natural fibers such as jute, coconut, and kenaf has also been investigated experimentally. However, their performance varies significantly depending on their durability, surface treatment, and compatibility with the cement paste (Bheel et al. 2021; Kameli et al. 2024; Nur et al. 2025). The synergistic effect of hybrid fiber systems combining steel with synthetic fibers or basalt fibers indicates improvements in both strength and toughness (Khan and Abbas 2025). The performance of fiber-reinforced mortar (FRM) also demonstrates promising potential (Akyüncü 2021; Doğan et al. 2022). Recent studies have also shown a trend of combining recycled aggregate-fiber reinforcement for sustainable and eco-friendly concrete development with improved mechanical performance (Ali et al. 2022; Doğan et al. 2022). Again, the special types of fibers such as carbon and basalt fibers have also been proved to have the potential of strengthening FRC (Doğan et al. 2022; Khan et al. 2025; Ünal et al. 2024). Overall, among the types of fibers used in concrete, steel fibers are widely appreciated and recognized for their strength, ductility, durability, and impact on tensile and flexural strength (Anas et al. 2022; Li et al. 2023). In contrast, synthetic fibers such as polypropylene, nylon, or hybrid fibers are known for improving the microstructural integrity of the matrix through crack resistance (Jahangir Qureshi et al. 2023).

The focus of FRC, however, has been conventional concrete-centered, while pervious or permeable concrete (PC) has also gained growing interest in the research arena due to its multiple advantages. It represents a porous concrete designed to allow water to infiltrate through for sustainable drainage and for smooth runoff management, especially in urban areas. This concrete contains cement and coarse aggregate with very lit-

tle or no filler, and is also referred to as no-sand concrete or no-fine concrete (ACI 522R-10 2010; Meininger 1988). The absence of fine aggregate results in high porosity through interconnected voids between coarse particles which eventually lowers its mechanical strength as compared to the conventional concrete (CC) used in construction (Lee et al. 2022).

Pervious concrete has the capability to mitigate surface runoff and recharge the groundwater making it a suitable material for sustainable pavement construction. Since, its limited load carrying capacity narrows down its structural application (ACI 522R-10 2010), pervious concrete is primarily used for low-traffic roadways with limited vehicular movement (Scholz and Grabowiecki 2007). Pavement construction with impermeable conventional concrete prevents rainwater from directly infiltrating into the ground creating environmental and climate issues (Yavuz 2024). Water accumulation on or near roadways during heavy or moderate rains is one of these issues which disrupts the traffic flow and safety (Yavuz 2024). Thus, the pavement construction in low-traffic regions such as pedestrian walkways and interior road networks in residential areas using porous concrete is highly recommended. It will facilitate the rapid water transmission into the ground, eventually preventing waterlogging on roads. The porosity of permeable concrete varies within a range, generally reported in the literature to be 15–25% (Xie et al. 2023) though the value recommended by ACI 522R is 15% to 35% (ACI 522R-10 2010). Regarding its mechanical strength, the compressive strength of PC may vary from 2.8 to 28 MPa and flexural strength ranges from 1.5 to 3.2 MPa, as suggested by researchers (Yavuz 2024). These strength properties are particularly influenced by various factors such as water/cement ratio, degree of compaction, binder content, aggregate type, and proportion (Ferić et al. 2023).

Research on pervious concrete has so far been focused mostly on its permeability. Different combinations of parameters such as content of cement and aggregates, type and size of aggregate, water content, additives, etc. have been explored to achieve balanced permeability (Ferić et al. 2023; Sun et al. 2025; Zhan and Yin 2024). In parallel with this, the mechanical strength properties of pervious concrete have also been extensively investigated. Recent initiatives on the enhancement of strength of pervious concrete using nano-materials and fibers have demonstrated promising results (Sun et al. 2025; Wu et al. 2023; Pehlivan 2022). Despite these advances in hydraulic and mechanical performance of PC, several research gaps remain. Optimization of both mechanical strength and porosity simultaneously continues to be a critical challenge, reflecting the more extensive need to balance mechanical performance with transport properties in sustainable concrete systems (Mahmud et al. 2025). Again, a comparative experimental analysis of fiber effect on both CC and PC under identical testing conditions is rarely reported in the literature. In addition, most experimental studies conducted on FRC rely on commercially manufactured fibers having standardized mechanical properties; little attention has been given to the use of locally available fiber materials. Furthermore, the role of fiber geometry combined with local resources

utilization in influencing the hydraulic functionality of pervious concrete remains insufficiently explored.

Therefore, this research work aims to experimentally evaluate the effects of locally sourced steel-wire fibers and commercially available nylon fibers on the mechanical properties of both conventional concrete and pervious concrete. These fibers offer potential advantages such as local resource availability, cost-effectiveness, and sustainability for developing regions. Moreover, by comparing both concrete typologies with similar fiber types and dosages, this study aims to provide insight into the balanced behavior of mechanical strength and hydraulic functionality, in terms of sustainable construction techniques.

2. Experimental Program

2.1. Materials and mix proportions

In this experimental work, fresh hydraulic cement (CEM I, Type A) was used as a binder for the preparation of both conventional and pervious concrete. River sand with FM of 2.68 and 19 mm downgrade stone chips were used as fine and coarse aggregates, respectively, in conventional concrete. The mix ratio was 1:1.5:3 by weight, with a water/cement ratio (w/c) of 0.45. The ratio was chosen to represent a typical structural grade concrete (target compressive strength of 20 MPa after 28 days of curing) used for most of the reinforced concrete (RC) structural components. For pervious concrete, a conventional mix ratio of 1:5 (cement: coarse aggregate) with w/c ratio of 0.33 was adopted without sand. The coarse aggregate consisted of 12 mm downgrade broken stone chips. The physical properties of the materials are given in Table 1. The selection of the maximum coarse aggregate sizes was intended to satisfy the functional requirements of the two concrete types commonly used in construction practice. Although cementitious mixtures without coarse aggregate are frequently adopted in some steel fiber-reinforced cementitious composites to facilitate fiber dispersion, the present study employed 19 mm downgrade (¾" downgrade) coarse aggregate for CC to represent typical structural concrete used in practice. In contrast, a 12 mm downgrade aggregate was used in PC to facilitate interconnected void formation while maintaining adequate aggregate interlock. Since larger coarse aggregates may influence fiber dispersion, relatively low

fiber dosages were adopted in this study and the controlled mixing procedure was followed to minimize the possibility of severe fiber balling and to promote satisfactory fiber distribution within the concrete matrix.

Steel fibers were obtained from readily available galvanized iron (GI) wires commonly used for binding in construction sites. The diameter of steel wires was 0.7 mm and a length of 60 mm was used, resulting in an aspect ratio (length/diameter) of 85.7. The nylon fibers were sourced from market-available twisted nylon ropes with a strand diameter of roughly 8–10 mm. The fiber diameter was 0.08 mm (80 μ m) and the fibers were cut into short discrete lengths of 20 mm with an aspect ratio of 250. Unlike industrially produced fibers with predefined mechanical and physical properties, the fibers used in this study were locally sourced and were not accompanied by manufacturer-specified data. The mechanical properties of these fibers were adopted from the literature and previous research works. This approach was followed because direct characterization of locally sourced fibers was beyond the scope of the present experimental program. Studies report a wide range of properties for the fibers depending on their type, manufacturing process, modifications, and geometric configuration. Thus, the properties used in this study are derived from the research sources that correspond to fibers with similar geometric and composite characteristics to ensure consistency in the experimental analysis. The geometric and mechanical properties of the fibers are summarized in Table 2, while Tables 3 and 4 present the mix proportions per unit volume for both CC and PC.

Fiber dosage was selected as percentage of cement weight, however, to facilitate comparison with previous studies, equivalent volumetric content of fibers is also shown in the respective tables. Fiber dispersion in concrete was carried out during dry mixing to avoid clustering and ensure uniform distribution of fibers, particularly at high dosage. All mixtures were prepared following the same mixing sequence, compaction procedure, and curing conditions to minimize variations associated with specimen preparation. The materials used in the lab work are illustrated in Figs. 1 and 2. Steel fibers were anchored at both ends for better bonding and nylon fibers were added in their original twisted shape obtained from the rope or strand to replicate real field conditions. Fig. 3 represents the gradation curves of the coarse and fine aggregates.

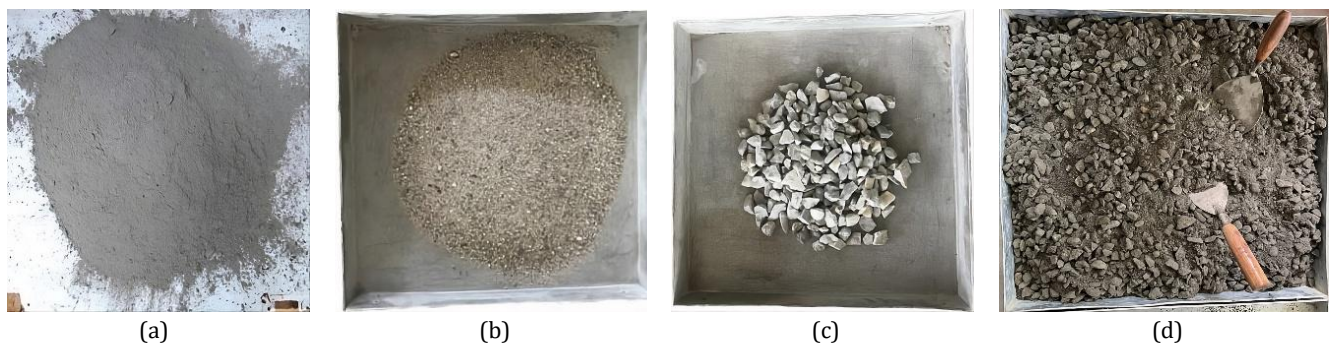


Fig. 1. Materials for concrete sample preparation: (a) Cement; (b) Fine aggregate; (c) Coarse aggregate; (d) Mixing of materials.

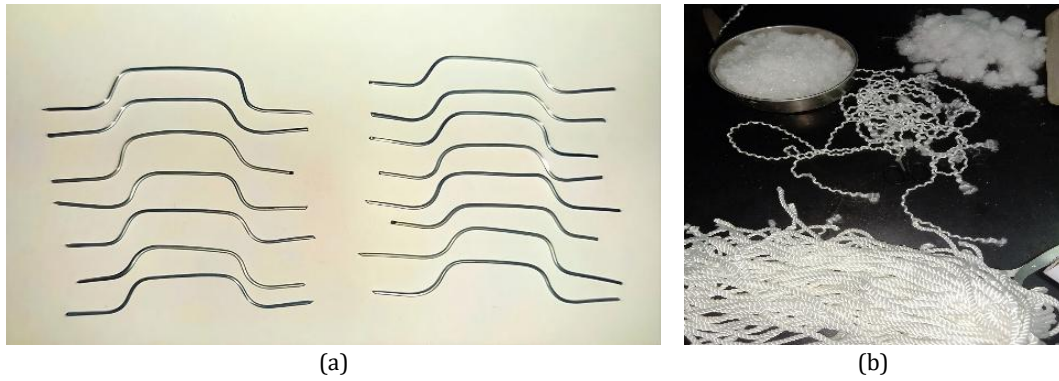


Fig. 2. Fibers used in concrete: (a) Steel fibers with end anchorage; (b) Nylon fiber.

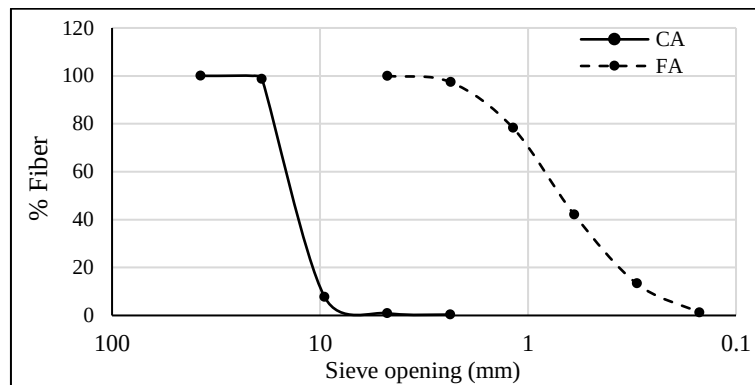


Table 3. Mix proportion for conventional concrete.

Fiber (%)	Cement (kg/m ³)	FA (kg/m ³)	CA (kg/m ³)	Mixing water (kg/m ³)	Fiber (kg/m ³)	Steel vol. fraction (%)	Nylon vol. fraction (%)
0.00	403	605	1209	181	0	0	0
0.25	403	605	1209	181	1.01	0.013	0.089
0.50	403	605	1209	181	2.02	0.026	0.177
0.75	403	605	1209	181	3.03	0.039	0.266
1.00	403	605	1209	181	4.04	0.052	0.354

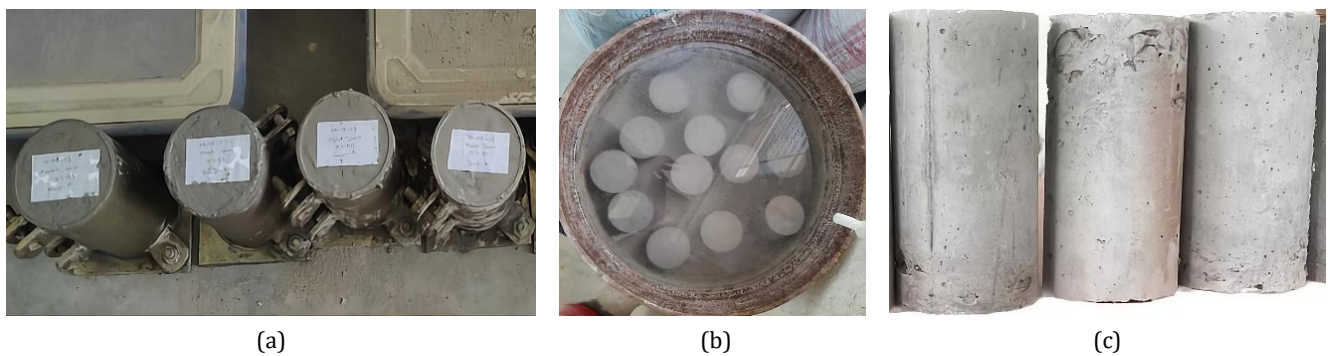
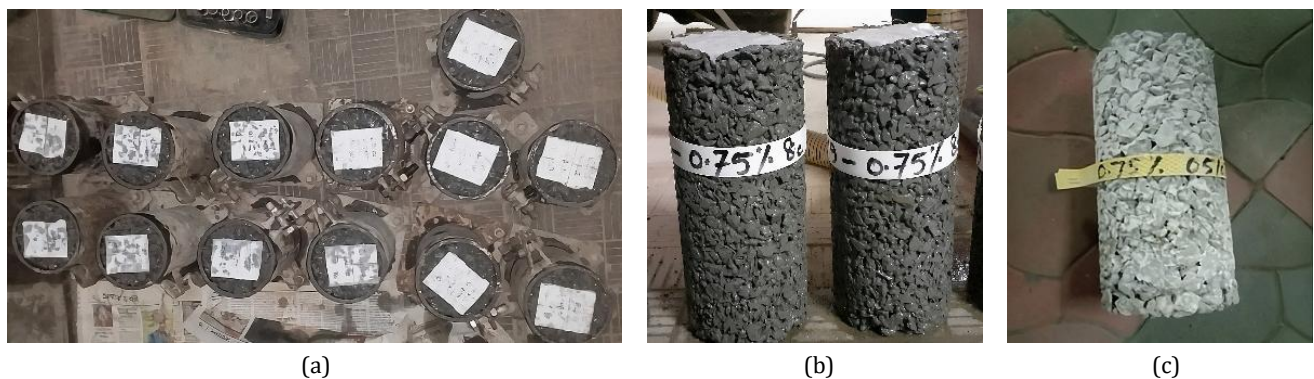
Table 4. Mix proportion for pervious concrete.

Fiber (%)	Cement (kg/m ³)	CA (kg/m ³)	Mixing water (kg/m ³)	Fiber (kg/m ³)	Steel vol. fraction (%)	Nylon vol. fraction (%)
0.00	300	1500	99	0	0	0
0.25	300	1500	99	0.75	0.010	0.066
0.50	300	1500	99	1.5	0.019	0.132
0.75	300	1500	99	2.25	0.029	0.197
1.00	300	1500	99	3.0	0.038	0.263

2.2. Concrete sample casting and curing

Cylindrical concrete samples of 100 mm diameter and 200 mm height (4 in. × 8 in.) were prepared with materials and mix ratio as stated in the previous section and summarized in Tables 3 and 4. Fibers were added separately as a weight percentage of cement (0.25%, 0.50%, 0.75%, and 1.0%). Samples were prepared following the standard mixing, casting, and compaction (Rodding) procedure stated in ASTM C192/C192M for conventional concrete. A total of nine (9) batches of the mix

were prepared for both CC and PC: 1 for the control specimen, 4 for steel fiber, and 4 for nylon fiber. The number of samples was determined as per the test requirements. For each mix, three (3) samples were prepared for each curing period (7 days and 28 days) under each test category (compressive and split tensile) e.g., three cylindrical samples for compressive strength after 7 days, three for compressive strength after 28 days, and so forth. This resulted in a total of 12 samples (3 samples × 2 curing periods × 2 tests) per batch or mix and with 9 batches, the total sample count was 108 for CC only.

**Fig. 4.** Preparation of conventional concrete: (a) Cast samples; (b) Curing; (c) Samples ready for testing.**Fig. 5.** Preparation of pervious concrete: (a) Casting; (b) Samples with steel fiber; (c) Samples with nylon fiber.

Pervious concrete samples were prepared in a similar manner using a mix ratio of 1:5. The mixing water quantity was determined by a trial method starting from a 0.30 w/c ratio. A certain quantity of material with the mentioned ratio was mixed and different amounts of water were added to check the consistency of the mix. After several trials, an optimum water/cement ratio of 0.33 was finalized based on the matrix's ability to retain its wet state without showing fluid-like behavior or a very dry condition. The fibers were added to the mix with the proportions mentioned in Table 4. Gradual mixing was adopted to prevent any clumping or balling of fibers inside the matrix. The number of samples followed a similar distribution as for CC with 3 additional specimens for the permeability test from each batch, which resulted in a total sample count of 135 for PC. The samples were prepared following

standard concrete casting procedure in ASTM C192/C192M with some modification for compaction as per ACI 522R. Figs. 4 and 5 show the preparation of concrete samples for testing.

2.3. Sample testing

Samples from each batch were cured in water for 7 and 28 days as per the test requirements. After curing, they were tested in accordance with the standard procedure for the compressive strength test and the split tensile strength test (ASTM C39 and ASTM C496, respectively). Prior to testing, each sample was dried at room temperature and then the sample dimensions were measured and their weight was noted to determine the density or unit weight. The testing arrangements are illustrated in Fig. 6.

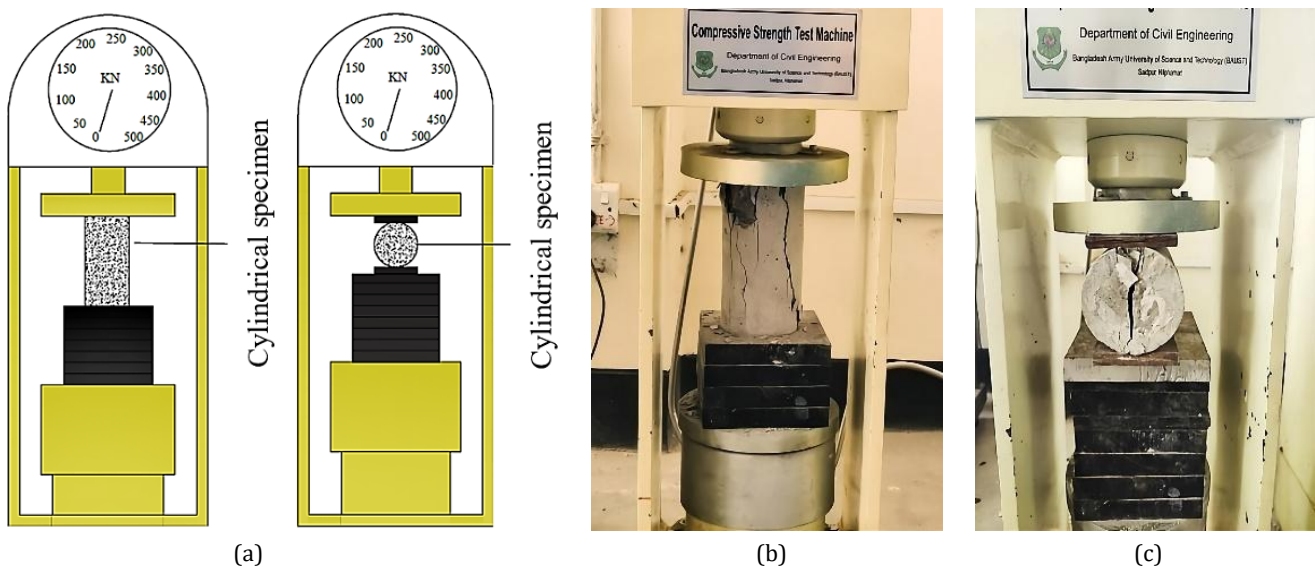


Fig. 6. Test set-up for compressive and split tensile strength: (a) Schematic diagram; (b) Compressive strength test; (c) Split tensile strength test.

For the permeability test, a disc-shaped slice of 50 mm thickness was taken out from the inside of the sample. The disc was then fitted into a PVC pipe of inner diameter of 100 mm to ensure proper fitting of the slice. Silicone putty was used around the perimeter of the disc adjacent to the inner surface of the pipe to prevent any potential water leakage or seepage from the sides. A constant water vol-

ume (1 L) was then poured over the disc inside the setup and the time for the water to pass through the sample was recorded. The test was conducted as per ACI 522R (Report on Pervious Concrete). The infiltration rate through the sample was calculated on the basis of discharge through the specimen and its cross-sectional dimension. Fig. 7 shows sliced specimens and the test setup.

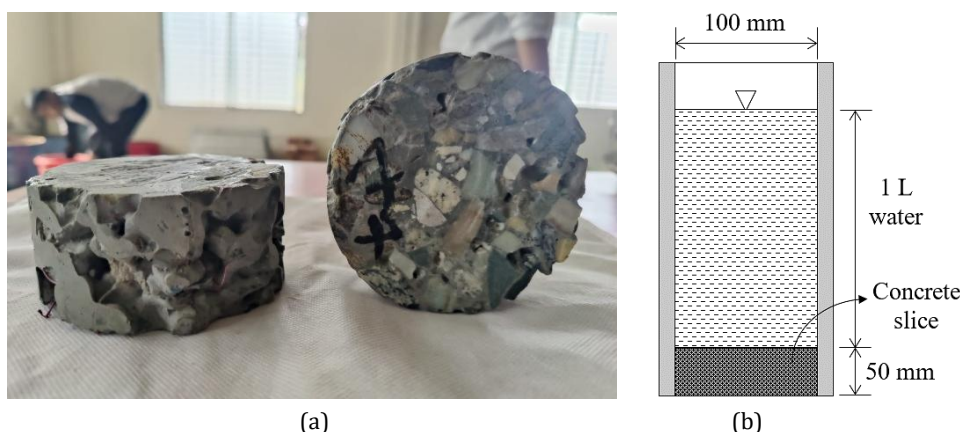


Fig. 7. Permeability test: (a) Concrete slice; (b) Schematic test setup.

3. Results and Discussion

3.1. Compressive strength of CC

The compressive strength of cylindrical samples from conventional concrete after 7 and 28 days of curing was determined. The control specimen after 7 days of curing achieved a strength of 14.26 MPa. After incorporation of steel fibers, the strength increased with the increasing content of fibers – the higher the percentage of fiber, the higher the strength, with maximum obtained for 1.0% fiber content. This increasing trend in particular is consistent with previous research as studies reported that steel fibers enhance the compressive strength of CC through improved crack-bridging capacity and better stress redistribution within the matrix (Amin et al. 2022; Zheng et al. 2024). Similar improvements have also been observed with increasing steel fiber dosage, although the optimum fiber content depends on the concrete mix and fiber characteristics (Zheng et al. 2024).

Regarding nylon fiber, the strength values show a fluctuating pattern – strength increased at 0.25% of fiber content and then decreased for the successive two percentages (0.50% and 0.75%) and increased again for 1.0%.

This behavior may be attributed to reduced fiber dispersion at higher nylon fiber dosages. The increased fiber content may increase the likelihood of fiber clustering, formation of localized voids and weaker fiber–matrix interaction. These factors may have contributed to reduced effectiveness of crack-bridging under compressive loading as suggested by studies on fiber-reinforced concrete and fiber-reinforced cementitious composites (Bakir and Yagmur 2026; Jahangir Qureshi et al. 2023; Nur et al. 2025).

In contrast, nylon fibers at 0.25% were more effective (22.3% increase) in this case than steel fibers (17.1% increase) with the same content. After 28 days of curing, the control specimen gained a crushing strength value of 22.97 MPa. Steel fibers slightly increased the strength, although not strictly in a linear trend, following a similar pattern as obtained from 7-day test. Nylon fiber once again showed a fluctuating pattern after 28 days of curing, due to the same potential reason stated earlier. However, this time, only one optimum value was obtained and that is for 0.25% which gained strength up to 24.15 MPa (5.1% increase), while the other contents of nylon proved to be ineffective. The graphical representation of data is shown in Fig. 8. Table 5 enlists the experimental data obtained.

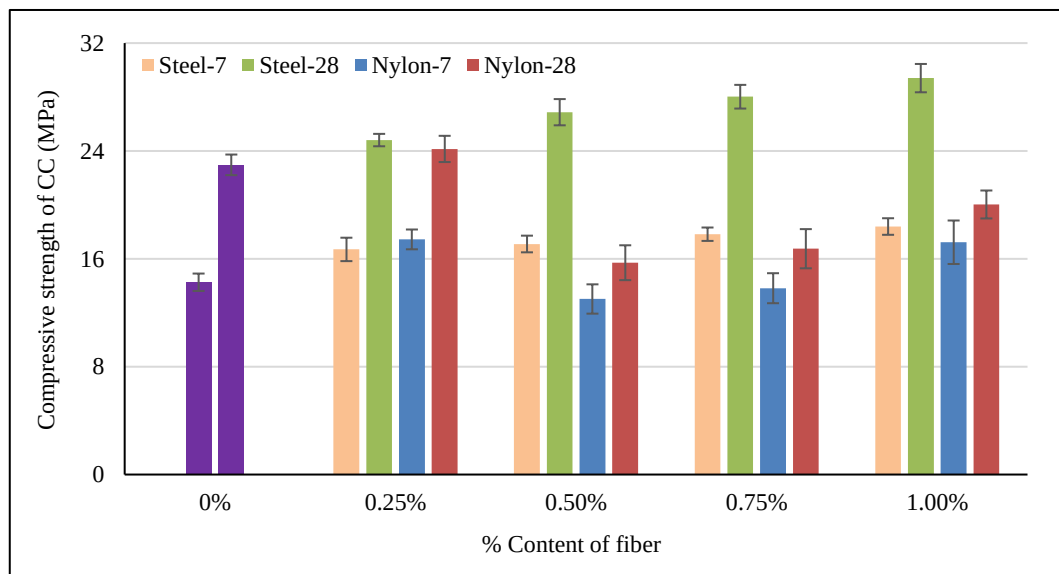


Fig. 8. Compressive strength comparison for conventional concrete.

(Note: The first two bars at 0% represent the strength values of CC after 7 and 28 days of curing, respectively.)

3.2. Split tensile strength of CC

Experimental data of the split tensile strength test shows that the control specimen gained a strength of 1.97 MPa after 7 days of curing. The addition of steel fiber followed the same pattern as for 7-day compressive strength test data – the higher the fiber content, the higher the strength. Maximum strength was obtained at 1.0% fiber content. Nylon fibers also followed the previous pattern: 0.25% and 1.0% increased the tensile strength. The 28-day tensile strength was similarly influenced. Nylon fiber showed an optimum fiber content at 0.25%, with an increase in strength of about 12.0%, while other percentages remained ineffective (similar to that observed for the compressive strength). The ob-

served enhancement in split tensile strength may be attributed to the crack-bridging action of the fibers across the tensile cracks. Higher crack-resistance provided by steel fibers may be attributed to their greater stiffness and stronger mechanical bond with the cement matrix, thereby improving tensile load transfer (Gul et al. 2021; Koo et al. 2023; Sitorus et al. 2025), highlighting the broader importance of fiber–matrix bond quality for effective stress transfer (Tarhan et al. 2025). In contrast, nylon fibers are more effective in controlling the initiation and propagation of microcracks at lower dosages which is consistent with findings of previous experimental studies (Nur et al. 2025). However, increasing the nylon fiber content may reduce fiber dispersion and fiber–matrix interaction, which can limit their contribu-

tion to tensile strength. Similar dosage-dependent behavior is observed in reported studies on nylon fiber-reinforced concrete. Findings demonstrated an improved crack control at lower fiber contents, while excessive fi-

ber addition reduced the effectiveness due to weaker fiber–matrix interaction and poorer fiber distribution (Ali et al. 2022; Bheel et al. 2021). The graphical representation of the strength values is given in Fig. 9.

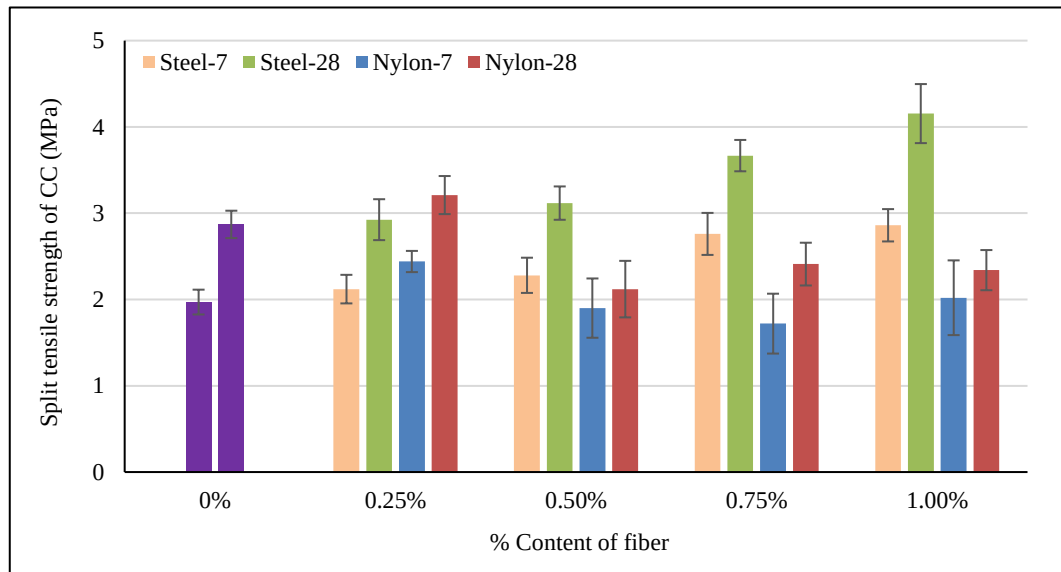


Fig. 9. Split tensile strength comparison for conventional concrete.

(Note: The first two bars at 0% represent the strength values of CC after 7 and 28 days of curing, respectively.)

3.3. Failure pattern of CC

The control specimen from conventional concrete showed failure patterns typically observed in compression and tension tests. However, the addition of fibers influenced the failure modes. During compression testing, fibers prevented the total collapse or detachment of aggregates and in the split tensile test, fibers, especially

with higher content, prevented the sample from being split apart longitudinally, as illustrated in Fig. 10. The observed failure patterns suggest that the fibers delayed crack opening and restrained crack propagation through improved fiber–matrix interaction. This behavior is consistent with the crack-bridging mechanism of the fibers reported more comprehensively in fibrous concrete systems (Youssef et al. 2026).

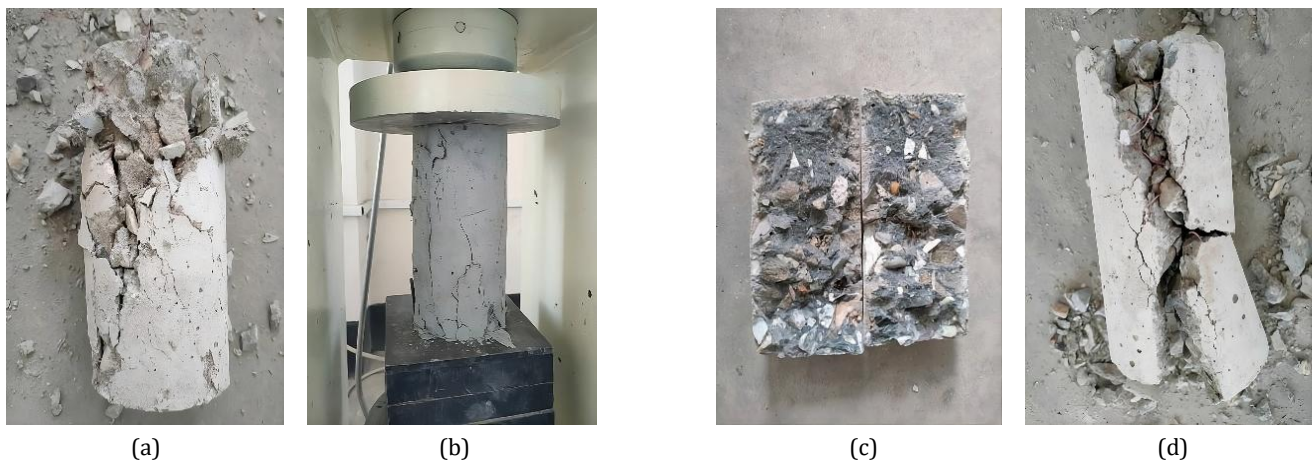


Fig. 10. Failure pattern of conventional concrete:

Compression failure without (a) and with (b) fiber; Split tensile failure without (c) and with (d) fiber.

3.4. Compressive strength of PC

The compressive strength of the control specimen of pervious concrete (PC-C) had values of 6.19 MPa and 9.59 MPa after 7 and 28 days of curing, respectively. Steel fibers helped strength gain at an early stage (7

days). Strength rose with increasing content of fiber up to 0.75% and then dropped at 1.0%. A similar trend for pervious concrete reinforced with steel fibers has been reported in literature, where moderate fiber contents improved compressive strength, whereas excessive fiber addition had an adverse effect (Lee et al. 2022). How-

ever, the compressive strength after 28 days of curing was effectively influenced by all fiber contents; with 0.75% showing optimum behavior. The observed decline in strength at higher fiber content (1%) may be attributed to the high volume of fibers affecting compaction and workability. This may have affected the interlocking between coarse particles at an early stage (Lee et al. 2022; Li et al. 2023). On the other hand, nylon fibers showed inconsistent and non-linear behavior in this regard. The effectiveness of fibers in pervious concrete also depends on the bond developed with the interconnected aggregate skeleton and the surrounding cement paste. The highly porous structure within the PC matrix

may reduce the available bonding area. Despite this, the fibers appeared to improve crack resistance and maintaining particle interlock at appropriate dosages. However, excessive fiber content may reduce these benefits by affecting fiber dispersion and matrix continuity (Ali et al. 2022; Nur et al. 2025). The strength increased after 7 days with 0.25% (18.4% increase) and 0.75% (13.0% increase) of fiber content, and had a similar effect on 28-day compressive strength as well. The changes in strength are illustrated in Fig. 11. A lower dose (0.25%) of nylon fiber was more effective than steel fibers with similar content in the pervious concrete after both curing periods.

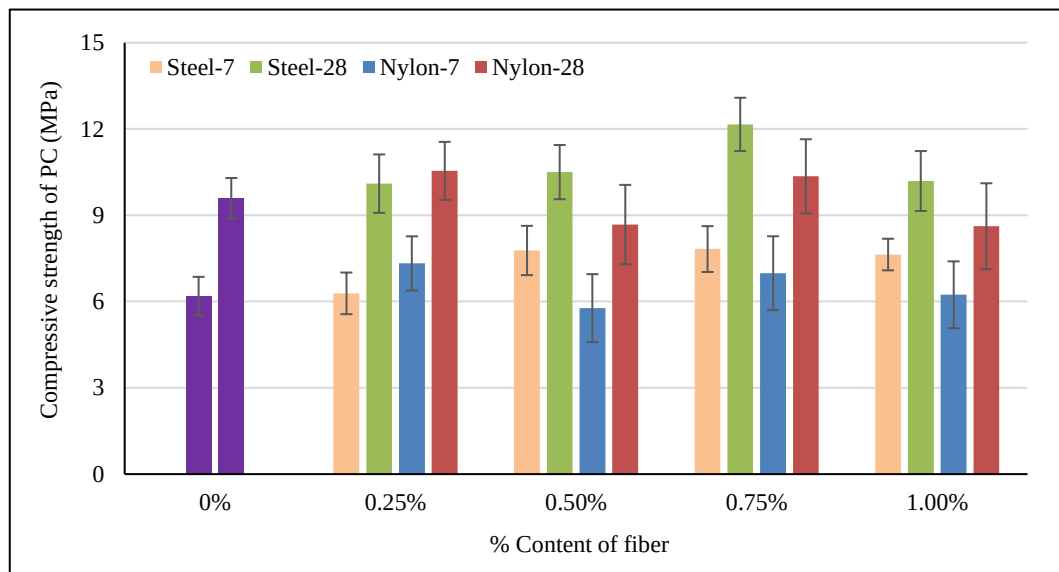


Fig. 11. Compressive strength comparison for pervious concrete.

(Note: The first two bars at 0% represent the strength values of PC after 7 and 28 days of curing, respectively.)

3.5. Split tensile strength of PC

The split tensile test was conducted on the same samples and the control specimen of PC achieved strength of 0.54 MPa and 1.61 MPa after 7-day and 28-day tests, respectively. Steel fibers improved the tensile load resistance for both curing ages. This behavior may be attributed to their high toughness and elastic modulus (Lee et al. 2022; Sitorus et al. 2025). The capability of nylon fiber in controlling tensile cracks after 7 days of curing was also noteworthy. Its influence on the 28-day split tensile strength was more impactful than that of steel fiber. Nylon fiber at 0.25% boosted the strength up to 33.7%, whereas steel fiber with the same content showed a 19% strength gain. A similar enhancement in tensile behavior due to the crack-bridging ability of nylon fibers has also been reported by Nur et al. (2025). The remaining fiber contents also enhanced the split tensile strength, although the response was not consistent. Steel fibers at 0.75% contributed to 27.8% increase in split tensile strength after 28 days.

The higher percentage increase in strength with steel fiber may be influenced through high durability, strength, and stiffness of the fiber itself as compared to nylon fibers. Again, the quantity of steel fibers per volume is smaller than that of nylon fibers due to density

variation. Large amounts of nylon fiber may contribute to the reduction in split tensile strength, which can be ascribed to the effect of low self-stiffness, flexibility, and non-uniform distribution. Possible clustering and lump formation within the concrete matrix may reduce the uniformity of the mixture and create local weak zones with poor crack bridging capacity (Ali et al. 2022). However, nylon fibers at a small dosage appeared to be more effective in resisting microcrack formation, whereas steel fibers were more effective in limiting the propagation of macrocracks. Fig. 12 illustrates the strength values of the split tensile test for PC. The experimental data are summarized in Table 5 with percentage change in strength.

3.6. Failure pattern of PC

The failure patterns of control specimens from pervious concrete showed typical bond failure between coarse particles, localized in weak regions (usually at top or bottom of samples). However, the fibers prevented the samples from being torn apart under both compression test and in split tensile test. The fibers, even after the strength was compromised, prevented the total split and held the detached portions together. Higher fiber content appeared to be more effective in holding the bro-

ken parts together. Some of the failure patterns are shown in Fig. 13. The overall performance of nylon fiber in resisting and bridging tensile cracks between particles may be associated with its larger numbers of fibers per vol-

ume compared to that of steel fibers. These observations suggest that the fibers remained effective in bridging cracks and maintaining the integrity of the porous concrete matrix despite its interconnected void structure.

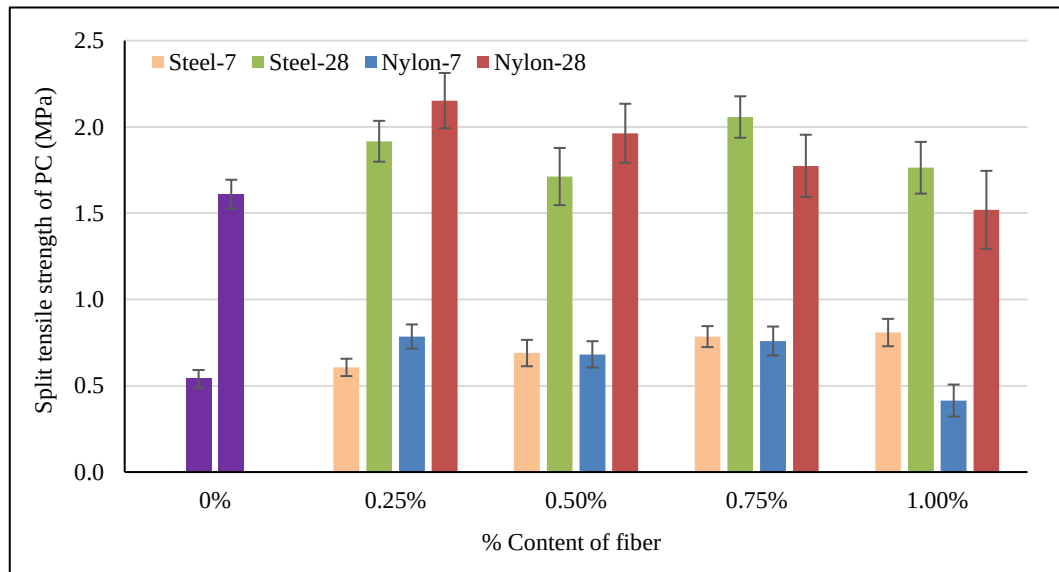


Fig. 12. Split tensile strength comparison for pervious concrete.

(Note: The first two bars at 0% represent the strength values of PC after 7 and 28 days of curing, respectively.)

Table 5. Strength test results of concrete specimens.

Sample ID	Fiber (%)	Compressive strength (MPa)				Split tensile strength (MPa)			
		7-days	% Change	28-days	% Change	7-days	% Change	28-days	% Change
CC-C	0.00	14.26 ± 0.65	–	22.97 ± 0.76	–	1.97 ± 0.14	–	2.87 ± 0.16	–
CC-S1	0.25	16.70 ± 0.87	+17.1	24.81 ± 0.46	+8.0	2.12 ± 0.17	+7.9	2.92 ± 0.24	+2.1
CC-S2	0.50	17.10 ± 0.62	+19.9	26.87 ± 0.97	+17.0	2.28 ± 0.20	+16.0	3.12 ± 0.19	+8.8
CC-S3	0.75	17.83 ± 0.50	+25.0	28.02 ± 0.88	+22.0	2.76 ± 0.24	+40.5	3.67 ± 0.18	+28.0
CC-S4	1.00	18.40 ± 0.61	+29.0	29.40 ± 1.05	+28.0	2.86 ± 0.19	+45.5	4.15 ± 0.34	+45.0
CC-N1	0.25	17.44 ± 0.73	+22.3	24.15 ± 0.97	+5.1	2.44 ± 0.12	+24.2	3.21 ± 0.22	+12.0
CC-N2	0.50	13.02 ± 1.09	–8.7	15.71 ± 1.29	–31.6	1.90 ± 0.34	–3.3	2.12 ± 0.33	–26.0
CC-N3	0.75	13.82 ± 1.11	–3.1	16.75 ± 1.45	–27.1	1.72 ± 0.35	–12.5	2.41 ± 0.25	–15.9
CC-N4	1.00	17.23 ± 1.61	+20.8	20.03 ± 1.04	–12.8	2.02 ± 0.43	+2.8	2.34 ± 0.23	–18.3
PC-C	0.00	6.19 ± 0.67	–	9.59 ± 0.70	–	0.54 ± 0.05	–	1.61 ± 0.08	–
PC-S1	0.25	6.28 ± 0.72	+1.6	10.10 ± 1.02	+5.4	0.61 ± 0.05	+13.3	1.92 ± 0.12	+19.0
PC-S2	0.50	7.77 ± 0.86	+25.7	10.50 ± 0.94	+9.5	0.69 ± 0.08	+28.9	1.71 ± 0.17	+6.3
PC-S3	0.75	7.82 ± 0.80	+26.5	12.16 ± 0.92	+26.9	0.78 ± 0.06	+46.7	2.06 ± 0.12	+27.8
PC-S4	1.00	7.63 ± 0.55	+23.4	10.19 ± 1.04	+6.3	0.81 ± 0.08	+51.1	1.76 ± 0.15	+9.5
PC-N1	0.25	7.32 ± 0.94	+18.4	10.54 ± 1.01	+10.0	0.79 ± 0.07	+46.8	2.15 ± 0.16	+33.7
PC-N2	0.50	5.77 ± 1.18	–6.7	8.67 ± 1.38	–9.5	0.68 ± 0.08	+27.4	1.96 ± 0.17	+21.9
PC-N3	0.75	6.99 ± 1.28	+13.0	10.35 ± 1.29	+8.0	0.76 ± 0.08	+41.9	1.77 ± 0.18	+10.2
PC-N4	1.00	6.24 ± 1.16	+0.8	8.62 ± 1.49	–10.1	0.41 ± 0.09	–22.6	1.52 ± 0.23	–5.6

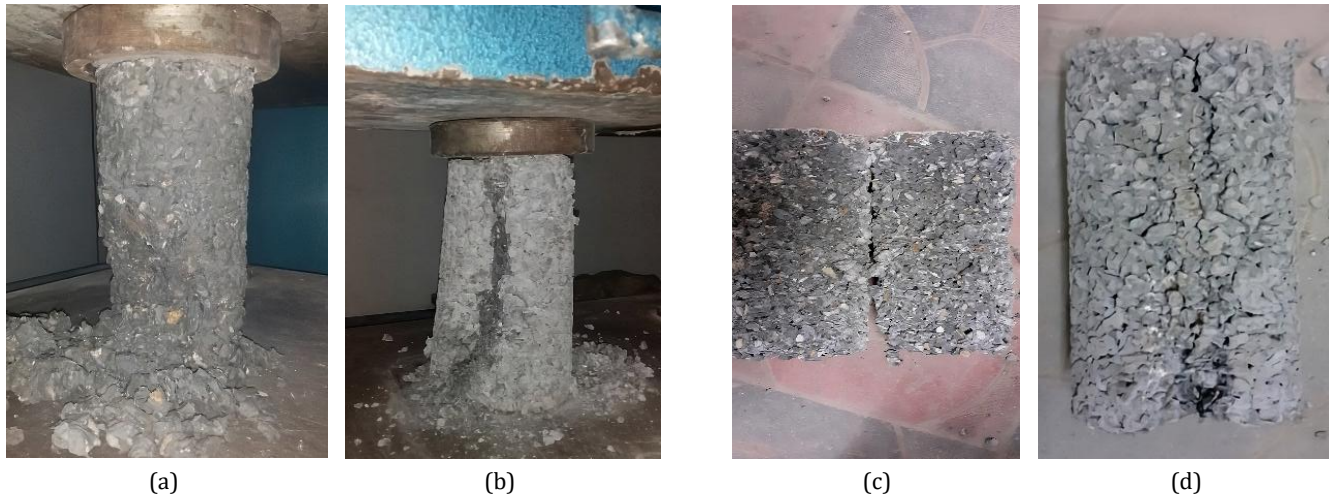
Notations: CC: Conventional Concrete; PC: Pervious Concrete; CC-C: Conventional Concrete Control Specimen;

PC-C: Pervious Concrete Control Specimen; S: Steel Fiber; N: Nylon Fiber;

Numbers 1,2,3,4 denote the chronological order of fiber % (S1: 0.25% steel fiber, N3: 0.75% nylon fiber, and so on).

Table 6. Density, porosity, and permeability data of concrete samples.

Fiber (%)	Density (kg/m ³) – CC		Density (kg/m ³) – PC		Porosity (%) – PC		Permeability (mm/s) – PC	
	Steel	Nylon	Steel	Nylon	Steel	Nylon	Steel	Nylon
0.00	2319.6 ± 33.2	2319.6 ± 33.2	1956.5 ± 13.8	1956.5 ± 13.8	15.65 ± 0.60	15.65 ± 0.60	0.253 ± 0.022	0.253 ± 0.022
0.25	2321.1 ± 42.4	2320.5 ± 20.0	1958.2 ± 20.2	1958.7 ± 12.6	15.58 ± 0.87	15.56 ± 0.54	0.293 ± 0.009	0.259 ± 0.008
0.50	2323.2 ± 36.1	2322.0 ± 18.8	1959.9 ± 16.4	1960.1 ± 9.0	15.51 ± 0.71	15.50 ± 0.39	0.309 ± 0.004	0.263 ± 0.017
0.75	2324.1 ± 29.1	2323.9 ± 12.8	1961.0 ± 9.6	1961.2 ± 15.5	15.46 ± 0.41	15.45 ± 0.67	0.287 ± 0.019	0.253 ± 0.004
1.00	2325.4 ± 26.4	2324.9 ± 10.1	1962.9 ± 16.4	1962.5 ± 21.0	15.38 ± 0.71	15.40 ± 0.91	0.229 ± 0.012	0.185 ± 0.003

**Fig. 13.** Failure pattern of pervious concrete: Compression failure without (a) and with (b) fiber; Split tensile failure without (c) and with (d) fiber.

3.7. Unit weight or density of CC and PC

The concrete samples were used to determine the variation of unit weight or density based on the direct ratio of their measured mass to geometric volume. The unit weight of pervious concrete is smaller compared to that of conventional concrete due to having a large amount of porosity. The incorporation of fibers influenced the density of the concrete samples by adding a small amount of weight, as anticipated. The slight variation may be associated with the mixing and distribution of fibers inside the matrix. A similar marginal increase in density with fiber incorporation has also been reported, where the increase was mainly associated with the presence of additional reinforcing material within the concrete matrix (Ali et al. 2022; Lee et al. 2022). The density data for both conventional and pervious concrete is shown in Table 6.

3.8. Porosity and permeability of PC

The absence of sand in pervious concrete creates interconnected voids or pores inside the matrix which allows the water to easily infiltrate through the medium. The porosity of the samples was calculated from the bulk density of conventional and pervious concrete as per ASTM C1754. The addition of fibers influenced the porosity and permeability, as illustrated in Fig. 14.

The permeability demonstrates a non-linear relationship with fiber content and was positively affected in the

initial stage of fiber incorporation. The porosity decreased with increasing fiber content in the pervious concrete, however, the permeability slightly increased for small fiber incorporation. Fiber contents of 0.25%, 0.50%, and 0.75% for steel fibers and 0.25% and 0.50% for nylon fiber improved the permeability (steel showing higher value), while 0.75% nylon had a neutral effect. For 1% fiber incorporation, permeability dropped in both cases. The improved permeability at lower fiber content may be attributed to the ability of the fibers to maintain the interconnected void within the aggregate skeleton. This may have facilitated the water flow through the interconnected pore networks. Similar permeability trends and their underlying mechanisms have been reported in previous studies investigating the influence of fibers on interconnected pore structure, tortuosity, and permeability (Wu et al. 2023). The proposed mechanisms are based on the observed permeability trends together with findings reported in the literature (Li et al. 2023; Wu et al. 2023; Xie et al. 2023), since direct microstructural investigation of the pore network was beyond the scope of the present study. A similar mechanism may also explain the behavior observed from nylon fiber. Since the quantity per unit volume of nylon fiber was larger than steel, their influence on permeability may differ because of their interaction with the pore structures. Lastly, the higher fiber content (1%) may have hindered the water flow by increasing the likelihood of partial blockage of interconnected pores within the matrix (Xie et al. 2023).

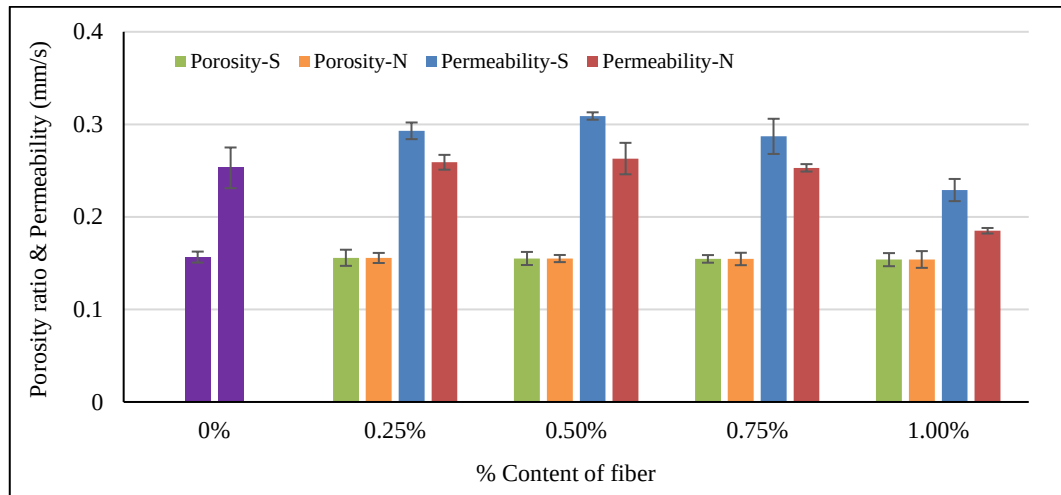


Fig. 14. Variation in porosity and permeability in pervious concrete.

(Note: The first two bars at 0% represent the porosity ratio and permeability values of PC, respectively.)

3.9. Comparison between the response of CC and PC

Pervious concrete, having lower material content and more voids, shows weaker strength (both compressive and tensile) as compared to the conventional one under

similar curing conditions. The increase in strength due to the fibers (steel and nylon) followed a similar pattern (Table 5). However, 0.25% nylon fiber in PC had slightly higher strength (2.15 MPa) than 0.5% content in CC (2.12 MPa), as illustrated in Figs. 15 and 16.

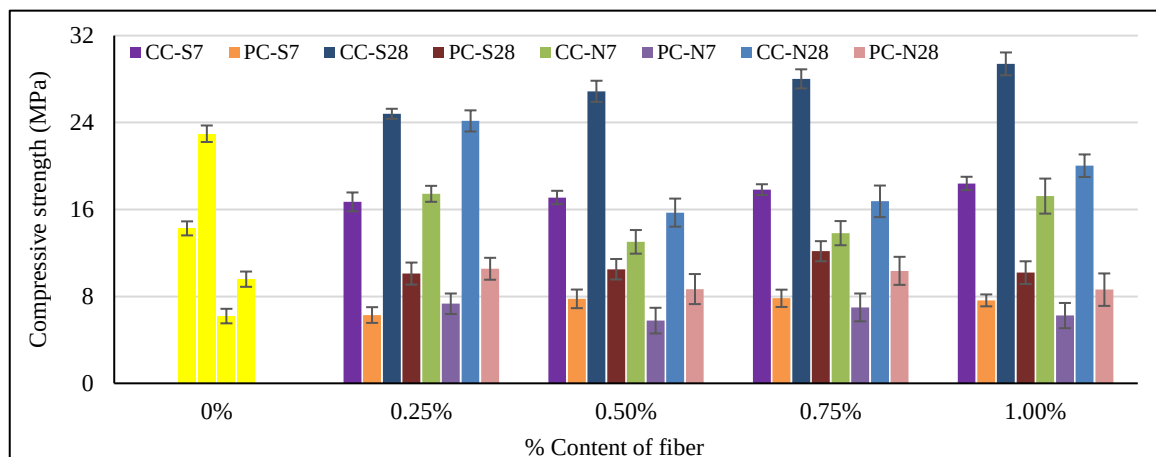


Fig. 15. Compressive strength comparison between CC and PC.

(Note: The first four bars at 0% represent the strength values of CC (7 and 28 days) and PC (7 and 28 days), respectively.)

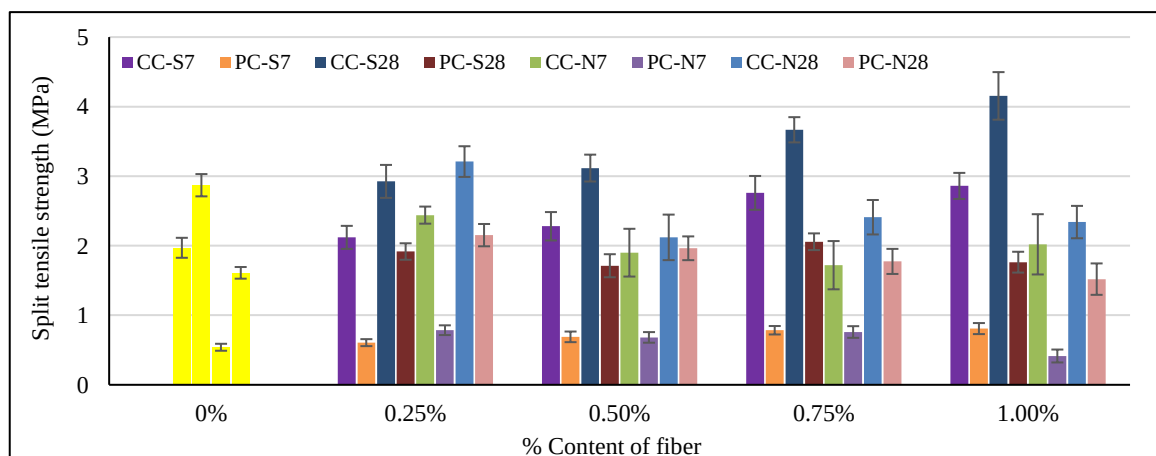


Fig. 16. Split tensile strength comparison between CC and PC.

(Note: The first four bars at 0% represent the strength values of CC (7 and 28 days) and PC (7 and 28 days), respectively.)

This behavior may be attributed to improved interfacial interaction between the coarse particles and nylon fibers due to their higher volume fraction. Moreover, fibers in the compact and impermeable CC might have been clustered inside the matrix. The agglomeration of fibers creates potentially weak regions responsible for crack development under load. While for pervious concrete, existing pore networks accommodate the fibers added later, which in turn create a bridging effect between particles through interfacial transition zones (ITZ). The relevant comparative analysis between them is illustrated in Figs. 15 and 16.

4. Conclusions

Two commonly used concrete types from two different construction sectors were strengthened using steel and nylon fibers to observe their mechanical performance. The findings indicate that, with controlled dosages, the compressive and split tensile strengths were affected by fiber incorporation. Steel fibers generally produced a consistent improvement in the mechanical performance of conventional concrete owing to their high pull-out resistance and high elastic modulus that contribute to a transition of the failure mode from brittle to ductile. In contrast, a large steel fiber content in PC led to a marginal reduction in strength, showing an inconsistent response. Nylon fibers demonstrated a dosage-dependent and non-uniform effect. Strength improvement at a lower dosage of nylon fiber may be attributed to high distribution efficiency, which enhances fiber-matrix interlocking across interfacial transition zones (ITZ). However, excessive content likely triggered premature failure due to fiber clustering and reduced matrix integrity. Fiber incorporation also affected the density, porosity, and permeability of pervious concrete. The findings demonstrate a trade-off between mechanical strength and hydraulic functionality of pervious concrete. From an engineering perspective, the findings of this study demonstrate that appropriate fiber selection and controlled dosage can improve the structural performance of both CC and PC. This can be achieved while maintaining their intended functional requirements. The results further support the feasibility of using locally available fibers as sustainable reinforcement materials in construction practice. Such an approach provides a practical basis for selecting locally available fibers in sustainable pavement and structural applications. Though the primary function of PC is to allow smooth drainage, this study suggests that with an optimum fiber content, improved mechanical strength can be achieved without significantly compromising permeability. This balanced response supports the effectiveness of pervious concrete for pavement construction with low to moderate traffic levels. Lastly, the present study focused on the mechanical properties of CC and PC in terms of compressive strength, split tensile strength, density, porosity, and permeability. Moreover, the mechanical property determination of locally sourced fibers, concrete workability and other mechanical properties of concrete such as modulus of elasticity, stress-strain behavior, and flexural behavior were beyond the scope of this study. Therefore, further

studies are recommended to examine these aspects, together with the effects of chemically modified fibers, microstructural characteristics and finite element analysis for a better understanding of the governing mechanisms behind the mechanical and physical behavior.

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Conflict of Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

AI Assistance

No AI-based tools were used in the preparation of this manuscript.

Author Contributions

All authors made substantial contributions to the conception and design of the study, acquisition of data, analysis and interpretation of data; drafted or critically revised the manuscript for important intellectual content; and approved the final version to be published.

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