SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

Study of the Mechanical and Physical Properties of Pervious Concrete Modified with Treated and Untreated Natural Coconut Fiber for Pavement

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ARTICLE INFO

Article history:
Received 8 June 2023
Received in revised form 11 August 2023
Accepted 24 August 2023
Available online 4 October 2023

Keywords:
Pervious concrete; coconut fiber; pavement; treatment; mechanical properties; physical performance

ABSTRACT

Pervious concrete pavements (PCP) are a novel material that numerous researchers are studying and focusing on. Its inexpensive cost, quick construction, and simple implementation are gaining favour. The aim of this study is to investigate the mechanical properties of pervious concrete pavement as well as the effects of modifying it with natural fibres such as coconut fibre. In this study, two types of coconut fibre were used: untreated (raw) fibre and alkali-treated fibre, as well as aggregates of various grades. By varying the amount of coconut fibre added by volume fractions of 3%, 6%, and 9%, the PCP mixes were generated. The fibre was treated with sodium hydroxide (NaOH) and is 2.5–3.5 cm long. The results showed that a 3% addition of treated natural fibre improved the mechanical properties of the PCP. Natural coconut fibre is able to be used as a concrete modification to improve its flexural behaviour and strength. According to the findings of this study, using 3% coconut fibre in the mix design of PCP at the age of 28 days improves tensile strength by 1.3 MPa, compressive strength by 4.8 MPa, and flexural strength by 1.92 MPa, whereas using 6% and higher fibres decreases flexural and split tensile and compressive strengths.

1. Introduction

One form of pavement used across the world is "impervious pavement," which is ultimately accountable for about two-thirds of excess water runoff and is also a contributor to hydrocarbon pollutants in metropolitan areas. Due to the soil's ability to maintain its purpose, stormwater runoff is a worldwide concern, especially in urban areas [1]. The volume of runoff water, which carries contaminants along it, is the greatest impediment to holding stormwater. According to Ferguson [2], pervious pavements are porous pavement systems with a connected system of void spaces within, which is an important step towards improving our environment and making it more sustainable. The primary objective of this pavement system is to enable hydrocarbon pollution to pass through, although it may ultimately collapse into the ground. According to Hamid *et al.*, [3], this novel

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https://doi.org/10.37934/aram.110.1.1121

technical paving technology reduces the need for and dependence on retention ponds and other conventional stormwater control methods, such as pipes beneath the ground, curbs, and gutters. This concept of pavement design was created to minimize storm runoff water in urban areas [4]. While elements such as pervious pavement permeability as well as porosity are highly substantial and have a direct effect on the entire soil system via hydrology, mechanical qualities, and impact on the environment [5].

Portland cement, water, coarse aggregate, admixtures, and generally barely any sand are the elements for pervious concrete pavement. This pavement system has a significant amount of porosity, making it ideal for concrete flatwork and allowing water to pass through from precipitation and other sources [6]. This involves runoff water management from replenishing ground levels and places. Because the combination comprises less mortar and little or almost no fine aggregate, it has a lower slump and stiffer consistency than other typical concrete compositions. In comparison with alternative concretes with large void percentages that are properly assembled, pervious concrete pavements attain greater strength, ranging from roughly 20.5 MPa to 3.5 MPa of flexural strength. Furthermore, a rise in community interest in sustainable buildings is driving individuals to choose pervious concrete [7].

Pervious concrete has a significant chance for obtaining recognition and garnering recognition due to its benefits in controlling stormwater runoff and preventing environmental damage [8]. This technology is the best approach to safeguard trees and a green nature in a pavement environment since different types of plants experience difficulties in an impermeable pavement environment because bridging water and air is difficult until the roots are in the soil. Nevertheless, pervious concrete pavement lets air and water flow past the neighbouring trees, which solves the problem. This paving technique also simplifies the construction of green parking spaces and paved urban areas for landscapers and architects. The PCP is a permanent, sustainable approach to the challenges humans encounter in cities [9].

The emphasized difficulty is the large space accessible for impermeable setups in urban contexts, which is predicted to give greater area throughout urban expansion and advancement. According to Sorvig *et al*., [10], impermeable regions suffer a struggle when runoff occurs, and infrastructure is desperately needed to sustain itself appropriately. Pervious concrete fundamentally serves as a low-volume paved surface, an alternate stormwater control system, and a low-speed operation. The hard concrete may be utilized to make a paved surface for a range of applications, whereas the unused area in concrete permits water to move through and drain from the pavement [11].

Before cement, fibres were used to reinforce weak materials. Fibres were shown to be useful in increasing the strain at peak load and providing extra energy absorption capabilities for reinforced concrete components and structures. Hamid *et al*., [3] recently discovered that increasing the static flexural strength of concrete, as well as its impact strength, tensile strength, ductility, and flexural toughness, resulted in an increase in the ductility of the concrete element. Natural fibres improve the mechanical, impact, and dynamic qualities of concrete. Natural fibres' microstructural qualities as composite components, such as elasticity, ductility, and energy absorption, increase earthquake resistance [21].

2. Materials and Methodology

2.1 Materials

The materials utilized for pervious concrete pavements are alike to those utilized in traditional concrete, with the exception of fine aggregate, which is totally removed from the list of components used in pervious concrete. The utilization of natural coconut fibres, as well as aggregate and changes with gradation, water, and cement, is the primary aspect of the current study. Each one of them, as well as their amount and performance, is further detailed in the sections that followed.

2.1.1 Cement

Type-I was employed in this investigation to make the pervious concrete mix. The amount and grade of cementitious material were determined in accordance with the American standards ASTM C 150 and C 1157.

2.1.2 Aggregate

Since coarse aggregate is narrow for gradation, its utility in this research is limited due to its composition. These gradations include the coarse aggregate ASTM C 33, No. 67 (19.0 to 4.75 mm), No. 8 (9.5 to 2.36 mm), and No. 89 (9.5 to 1.18 mm). The diameters of these aggregates range from 9.5 mm to 4.75 mm in this research. Because larger aggregates often have a texture that's rough, the use of narrow gradation is a significant characteristic. As a result, in this research, smaller in size was utilized since it is also viable for aesthetic reasons. According to specialists, a coarse aggregate of 9.5 mm is often utilized for pedestrian usage; hence, this investigation adopted the same approach. To produce the preceding concrete, these materials contained a rounded aggregate, also known as crushed stone, and an angular aggregate, also known as crushed stone. Although circular aggregates have significant strengths, angular aggregates are typically preferred.

ASTM D 448, which complies with pervious concrete for pavements, has been stated to be utilized for overall pervious concrete, whereas ASTM C 33 has been reported to be utilized for general pervious concrete. Furthermore, while constructing pervious concrete, saturated or close monitoring of the moisture conditions in the aggregate is necessary for the dry-surface state, which is nearly similar to ordinary concrete. This aggregate accounts for the free moisture in the aggregate. It should also be highlighted that water control is a major reason for using pervious concrete. Dry mixes that absorb water will lead to the dry mixture, resulting in reduced compression. More water in pervious concrete means a greater water-to-cement ratio in the finished product.

2.1.3 Fibers

The research utilizes the use of both treated and untreated natural fibres. Coconut fibres with a slit size of 2.5 cm to 3.5 cm are used. The comparison in this study is primarily intended to examine the variance in outcomes when enhanced with treated coconut fibres in the preceding concrete mix and regular coconut fibres in their natural state. The procedure technique for coconut fibres is described in the next section [12].

2.1.4 Treatment process for coconut fiber

Fibers are rinsed and washed three times with typical tap water to remove dust, dirt, and various other impurities. Following washing it properly, it is dried at room temperature for nearly two days or 48 hours. The dried coconut fibres are immersed in a 4 percent NaOH solution after drying. It was set at 20 degrees Celsius for half an hour or 30 minutes. Following the alkali soak, the fibre is rinsed several times with regular tap water to allow the absorbed alkali to seep into the strands. It dried for 24 hours before being placed in an oven at 50 °C to dry for an additional 8 hours [13].

2.1.5 Water

The water utilized in this study is standard tap water or potable water because it is a common routine usage of water for concrete. Furthermore, the water condition meets the requirement mentioned in ACI 301.

2.2 Mix Design Development

Design Mix In this research, "mix design" refers to the technique of selecting acceptable concrete materials and specifying their relative proportions to make concrete with the least amount of strength, cost-effectiveness, and durability. A certain percentage of cement and water, as well as graded aggregate, are essential for a sustainable and acceptable combination to attain strength qualities. This stage is critical for identifying the right quantities of each ingredient to maintain the quality of the pervious concrete mix. These mass ratios are often in the 4.0 to 4.5 range. The majority of them are A/C ratios, with total values ranging from 1300 kg/m^3 to 1800 kg/m^3. The researchers had previously used A/C ratios at the testing facility and saw a significant decline in strength. Water-to-cement ratios ranging from 0.27 to 0.36 are often utilised with proper chemical admixture inclusion, while ratios as high as 0.40 have been successfully used.

Because, unlike conventional concrete, the total paste content of pervious concrete is smaller than the void content between the aggregates, the relationship between strength and the water-to-cement ratio is unclear. A glimmer of water should be seen pouring off the aggregate in the mixture. A ball built from pervious concrete should not crush. It signifies that pervious concrete should be stiff. The next section discusses the proportions of the elements used in the combination. Materials were utilised with the option of include or eliminating fibres.

The initial mix was performed with no fibre to determine the maximum compressive strength, and after we determined the percentage with the greatest strength to withstand the load, the highest compressive strength percent findings were employed in the following mix, which contained fibre. The proportions utilized in the following mix when the compaction technique is applied are shown in Table 1. The compaction technique was used in two ways: (A) with a cylinder tamping rod and (B) with a straight tamping rod.

Table 1
Mix proportions

Mix.ID	Coarse.AGG (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	A/C	W/C	Maximum load (kg)
Mix 1A	1500	350	114	4.28	0.325	A 17143.6
1B						B 13336.8
Mix 2A	1500	370	118.2	4.05	0.319	A 19258.1
2B						B 12047.5
Mix 3A	1500	360	125.6	4.16	0.348	A 21541.4
3B						B 19438.9
Mix 4A	1600	380	132.8	4.21	0.349	A 38049.3
4B						B 22558.3
Mix 5A	1600	360	129.6	4.4	0.36	A 24057.0
5B						B 24341.8

Following the test to determine the optimal material percentage, the same experiment was carried out to investigate the impact of natural fibres in preceding pavement concrete. The fibres were classified as either untreated or treated. In this context, "untreated fibre" refers to fibre in its natural unprocessed state, whereas "treated fibre" refers to NaOH-treated fibre.

As shown in Table 2, various quantities of fibres were utilized in every experiment. In terms of compressive strength to handle the load, each of them achieved various outcomes.

Table 2
Proportion of Materials with Treated and Untreated Fiber

SP.ID	Coarse.AGG (kg/m3)	Cement (kg/m3)	Water (kg/m^3)	Treated Fiber volume (%)	Untreated Fiber volume (%)	A/C	W/C
PCP-0	1600	380	114	0	0	4.21	0.325
PCP-TF3	1600	380	118.2	0.3	0	4.21	0.319
PCP-TF6	1600	380	125.6	0.6	0	4.21	0.348
PCP-TF9	1600	380	116.9	0.9	0	4.21	0.307
PCP-UTF3	1600	380	132.8	0	0.3	4.21	0.349
PCP-UTF6	1600	380	129.6	0	0.6	4.21	0.36

2.3 Mixing Samples Treatment and Tests

After curing for an acceptable duration (see Table 3, "Age at Testing"), the demoulded specimens are removed and evaluated using conventional testing equipment. Table 3 lists the tests performed to establish PCP characteristics.

Table 3
Tests lists for the PCP specimens

List of Tests	ASTM Standard	Testing Age
Compressive strength (CS)	ASTM C39	7,14 and 28 days
Flexural strength (FL)	ASTM C 78-02	7and 28 days
Split tensile strength (STS)	ASTM C496	7 and 28 days

2.3.1 Compressive strength

This test was carried out in accordance with the norms of the Compressive Strength Test ASTM C39 (ASTM, 2004a) in this study. This test demonstrates the pavement's capacity to withstand axially directed compressive stresses. In addition to those criteria, cylindrical specimens were utilized for this test based on the ASTM size standards. The typical test technique utilized here, nevertheless, is intended for evaluating concrete, although it is also a viable option for assessing inflexible pervious pavements. For the time being, no particular test technique has been approved for this application. The binder is a fragile, quantifiable holding arrangement for the prior pavement mixture's coarse aggregates and other components. The purpose of this test was created to determine how much compressive force the binder can tolerate without failing.

$$f_m = \frac{p}{A} \tag{1}$$

where f_m = compressive strength (MPa), P = total maximum load (N), and A = area of the loaded surface (mm^2).

2.3.2 Flexural strength (FS)

This durability test follows the guidelines of ASTM C 78-02 standards and is valid for beams with dimensions of 152.4 mm x 152.4 mm x 508 mm with 66 three-point loads. Flexural strength is found to be the modulus of rupture as a result of this equation. The modulus of rupture may be calculated using the formula as follows:

$$F_s = \frac{PL}{bd^2} \quad (2)$$

where P indicates the applied load. The length of the specimen is L, the width of the beam is b, and the depth of the beam is d. According to Crouch *et al.,* (2003), the formula is derived from elastic theory, which asserts that it precisely displays elastic behaviour until the time of collapse. The test specimens must be even, devoid of scratches or hovels, and have perpendicular sides to the top and bottom.

2.3.3 Split tensile strength (STS)

The splitting tensile strength test on the samples was conducted following the specifications of the ASTM C496 (2008). Sample cylinders of 100 x 200 mm were prepared and used for the test; the applied load was directed from a 1000 KN capacity load machine. The load was applied continuously up to failure. The load continuously exerted without shock at a steady rate (ranging from 689 - 1380 kPa/min) until specimens' failure. Upon failure, the maximum indicated load on the testing instrument was noted. The splitting tensile strength machine used in this study on the HWC sample. The splitting tensile strength was estimated using Equation 3 from the average of three-cylinder measurements.

$$T = \frac{2P}{\pi Ld} \quad (3)$$

where T= splitting tensile strength (MPa), P = maximum applied load (N), L = length (mm), d = diameter (mm).

3. Results

3.1 Compressive Strength

Compressive strength tests on prior concrete pavement samples were conducted over 7, 14, and 28 days, respectively. The curing ages of the specimens, as well as the results and comparisons within the samples, are defined in Table 4 In the laboratory, compressive strength tests were done on three separate samples: control, treated, and untreated samples. Those samples were also divided depending on the proportion of fibre in each, for example, 3%, 6%, and 9% of fibre samples. Each specimen exposed to the compressive strength test was recorded, and the data was analysed by the machine to determine compressive strength.

The results provided (Figure 1) represent the maximum compressive load that the samples being prepared can sustain before breaking down or cracking. Adding fibres to the preceding concrete mixture also increased the porosity of the PCP mix, diminishing its compressive strength.

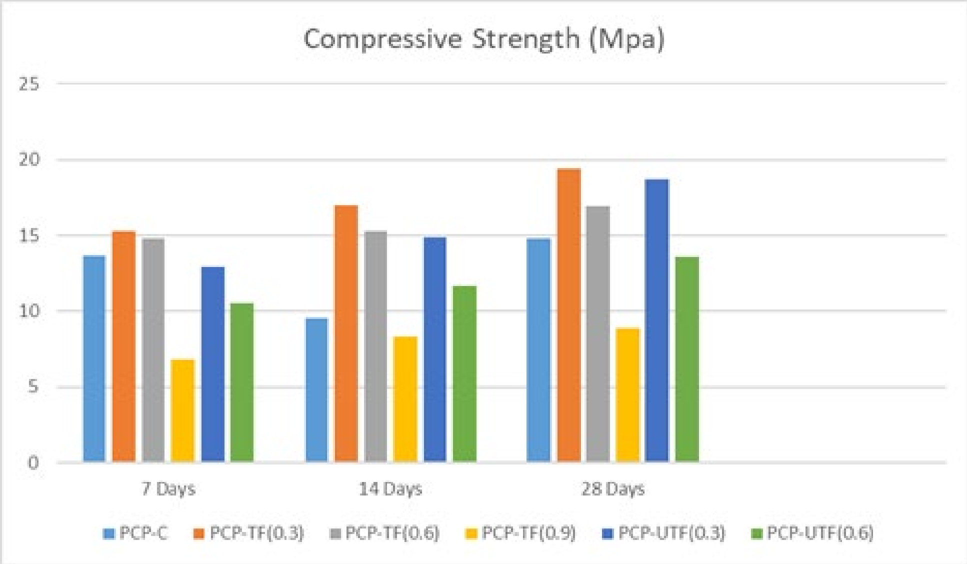

Fig. 1. Compressive Strength Test of PCP

The test results table compares the compressive strength with various mixes with the variation of their proportions used in their mixes at various curing ages, such as 7, 14, and 28 days. There are no conventional ranges established as standards for compressive strength; nonetheless, in laboratory-conducted testing, compressive strength is determined to be in the range of 3.5 MPa to 28 MPa (500 to 4000 psi) for the usage of varied applications. Therefore the result of this research, the compressive strength of the prior concrete mixture finds increased in its compressive strength in 28 days' results of 4.58 MPa when enhanced by 3 percent of alkali-treated fibre with concrete mix, whereas the trend indicated a reduction in compressive strength when the treated fibre was added with a higher proportion, such as when the researcher added treated fibre of 6% and 9%, obtaining results of -2.44 and -8.09, respectively. Furthermore, the results show an increasing tendency with untreated fibre when added from control to 3% of fibre, with a rise of 3.9 MPa recorded but a reduction of -5.15 MPa recorded when added to 6% of fibre. Since the compressive strength findings demonstrate, all of the specimens satisfied this requirement after 28 days of curing, but the best performance was obtained when 3% of alkali-treated fibre was included in a prior concrete mix. The slope of the 28-day compressive strength test when analysed is shown in the Figure 2.

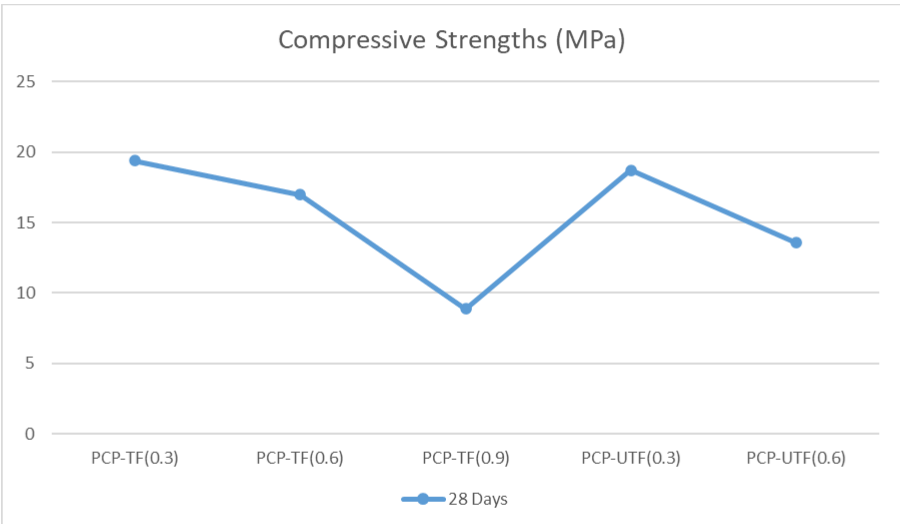

Fig. 2. The slope of 28 days' compressive strengths

Earlier research on the inclusion of natural fibres indicated that fibre adding lowered compressive strengths, which was also attributable to void formation in extremely low cement-content concrete. Nevertheless, a few studies stated that including fibres in the concrete improves the compressive strength [14]. additionally, several neutral outcomes were discovered, stating that fibre added no value in terms of an increase or decrease in the compressive strength of coconut fibres in the mix [15]. The findings of this study reveal that when above three percent of treated and untreated fibre is added, the compressive strength decreases, however in the control sample, the compressive strength increases when the mix is amended with 3% of treated natural fibre. As a result, it is possible to determine that 3% is the greatest match for usage in the modification of pervious concrete pavement.

3.2 Flexural Strength (FS)

The experiment was performed to determine the flexing or bending qualities of the PCP specimen. The procedure includes sandwiching a sample of the beam between two points and applying a load to the third point, often known as a 3-point bend. In certain practises, the exact same test is conducted on four points and is called as "four-point bend testing." According to Timoshenko and Goodier (1970), the four-point test bending was used in this study to decrease the exaggerated bending resistance caused by the load-spreading effect at the site of load presentation. Other factors to consider are the researcher's wish to avoid making mistakes during the experiment and the effect of torsion on deflection measurements [16].

The four-point approach was used to measure flexural strength in this study. The bending findings of all samples are given in Figure 3. In a laboratory, the cylindrical pervious concrete samples were examined. When treated alkali fibre was added to the concrete mixture, the flexural strength increased by 1.92 MPa. Nonetheless, when the fibre percentage was increased by more than 3%, the flexural strength looked to be decreasing, with losses of -1.62 MPa and -2.35 MPa when increased by 6% and 9%, respectively. Furthermore, when 3% and 6% untreated or raw fibre were added, the flexural strength fell by -3.12 MPa and -0.53 MPa, respectively. Figure 3 depicts a graph showing the results of flexural strength tests on prior concrete pavement specimens.

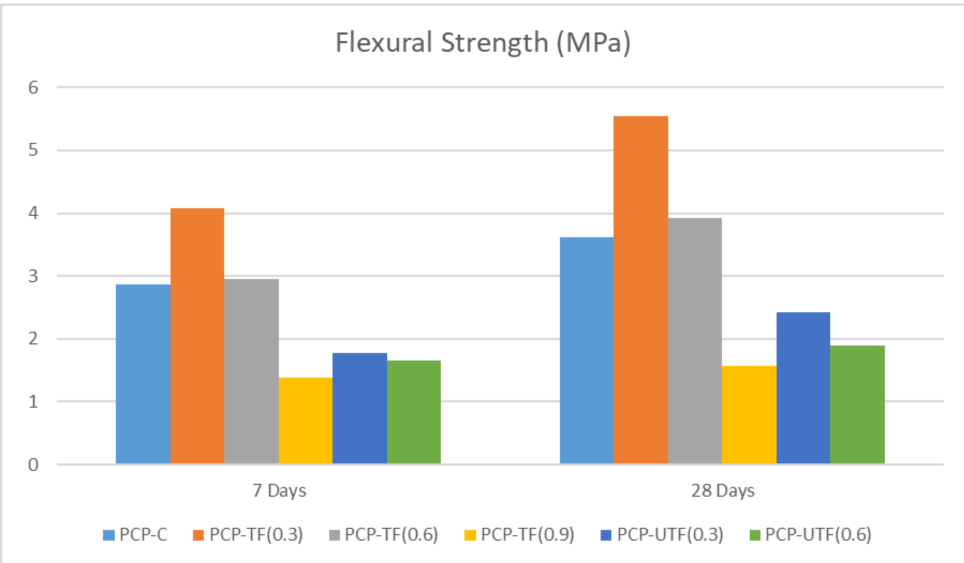

Fig. 3. PCP Flexural Strength Test

The measurements carried out in this study revealed some variance with increases and declines in PCP flexural strength. The researcher presented the outcomes of this variation in tabular form in Table 4. It is possible to infer that 3% alteration with treated fibre is the best option for increasing flexural strength.

Table 4
Flexural Strength of PCP with coconut fibres

	Control	3% TF	6% TF	9% TF	3% UTF	6% UTF
Flexural Strength	5.54	1.92+	1.62-	2.35-	3.12-	0.53-

3.3 Split tensile strength (STS)

The split tensile test was carried out in the laboratory using prior concrete pavement samples; it included control, treated (alkali-treated coconut fibre), and untreated (raw coconut fibre) samples. The studies were conducted on 7 to 28 ages. The researchers discovered that adding or removing treated or untreated coconut fibres increases or decreases strength. The researcher summarised the findings in the form of a chart in Figure 4, which shows the increase and decrease in the strength of the samples due to changes in the amount of fibre. As stated by Copalaratnam and Gettu [17], the splitting tensile strength and tensile strength of control and fibre PCP specimens increase with the amount of fibres, and fibre interaction can result in post-cracking hardening behaviour. The outcomes of this study show a similar conclusion, but differences in fibre amounts are discovered since the researcher examined the split tensile test with varying proportions of fibre included as 3%, 6%, and 9% with treated and untreated forms of it. The results are depicted as a chart in Figure 4.

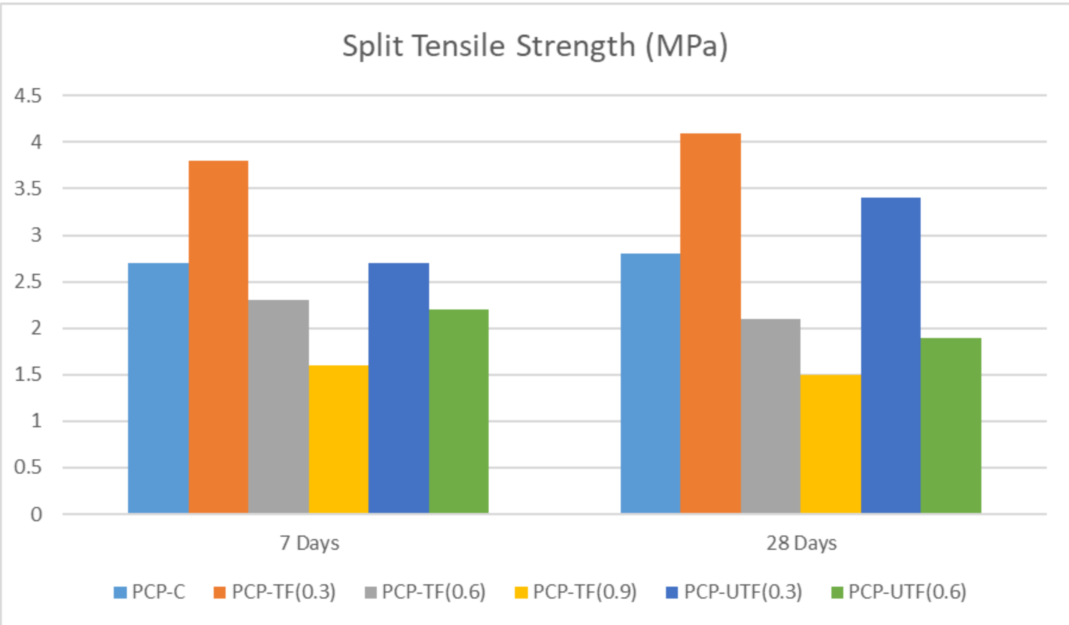

Fig. 4. Split Tensile Test Chart

When compared to previous changes, alkali-treating natural fibres with PCP cylinders resulted in higher tensile splitting strength. This boosts the PCP's tensile split strength because natural fibres assist in the transport of weight through shear stress at the interface. A strong connection between the natural fibre and the matrix is required for this. The difference in splitting tensile strengths between practical specimens was greater after 28 days than after 7 days. At 3% modification with the mix, the greatest splitting tensile strength value for PCP with the treated fibre is attained. In addition, a 0.6 MPa rise was seen in the alteration of 3% untreated fibre. In addition, as indicated in tabular form in Table 4, the decline was found in all other outcomes. This table depicts the variance in the findings based on the samples' 28-day age.

Table 5
Tensile Strength of coconut fibres PCP

	Control	3%TF	6% TF	9% TF	3% UTF	6% UTF
Tensile Strength	2.8	1.3+	2-	0.6-	0.6+	1.5-

The findings of this study, as well as those of other researchers [18-20], indicate the tensile strength of PCP enhanced with the addition of fibre, with the amount of fibre in the concrete matrix influencing the tensile strength in the majority of the mixtures.

4. Conclusions

The compressive strength test, flexural strength test, and split tensile test employed in this study were all done at the USM laboratory. The strength test results reveal that using or modifying 3% alkali-treated coconut fibre with the pervious concrete pavement produces the best results. This will improve all three of the PCP's strengths and will be useful and relevant to the paving system.

Acknowledgement
This research was not funded by any grant.

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