Civil Engineering and Architecture 13(3): 1840-1857, 2025 http://www.hrpub.org
DOI: 10.13189/cea.2025.130329

Development and Evaluation of Sustainable Concrete: Effect of Coffee Husk Ash and Pineapple Fiber on Mechanical Properties

Ariana Nicole Grados Hinojosa, Jheny Zenaida Romero Jimenez, Maria Estela Quispe Sedano, Marko Antonio Lengua Fernandez*

Faculty of Civil Engineering, Continental University, Perú

Received January 21, 2025; Revised March 6, 2025; Accepted March 23, 2025

Cite This Paper in the Following Citation Styles

***(a):** [1] Ariana Nicole Grados Hinojosa, Jheny Zenaida Romero Jimenez, Maria Estela Quispe Sedano, Marko Antonio Lengua Fernandez , "Development and Evaluation of Sustainable Concrete: Effect of Coffee Husk Ash and Pineapple Fiber on Mechanical Properties," Civil Engineering and Architecture, Vol. 13, No. 3, pp. 1840 - 1857, 2025. DOI: 10.13189/cea.2025.130329.*

***(b):** Ariana Nicole Grados Hinojosa, Jheny Zenaida Romero Jimenez, Maria Estela Quispe Sedano, Marko Antonio Lengua Fernandez (2025). Development and Evaluation of Sustainable Concrete: Effect of Coffee Husk Ash and Pineapple Fiber on Mechanical Properties. Civil Engineering and Architecture, 13(3), 1840 - 1857. DOI: 10.13189/cea.2025.130329.*

Abstract The improvement of concrete properties is critical for advancing sustainable construction materials, and this study introduces an innovative approach to achieve this by repurposing agroindustrial waste. Peru faces a growing environmental challenge due to the vast amounts of agricultural residues generated, particularly from coffee and pineapple production. This research demonstrates how coffee husk ash (CHA) and pineapple fiber (FHP) can be effectively incorporated into concrete to enhance its mechanical performance while addressing waste management issues. The experimental program focused on developing a concrete mix with a target strength of 210 kg/cm², integrating CHA and FHP as sustainable additives. These materials underwent specific pre-treatment processes—drying, calcination, and sieving for CHA, and drying and cutting for FHP—before being introduced into the mix in varying proportions. The mechanical properties of the modified concrete, including compressive, tensile, and flexural strengths, were evaluated through rigorous testing. Results revealed that an optimal combination of 1.60% CHA and 1.10% FHP significantly enhanced the concrete's performance, achieving a compressive strength of 271.55 kg/cm², a tensile strength of 32.71 kg/cm², and a flexural strength of 82.81 kg/cm² at 28 days. These improvements represent a remarkable leap in material strength compared to standard concrete. However, excessive dosages of additives led to slight declines in performance, emphasizing the importance of dosage optimization. This study highlights the dual benefits of incorporating agroindustrial waste into concrete: improving the mechanical properties of construction materials and contributing to environmental sustainability. By transforming waste into valuable resources, the research provides a practical and scalable solution for the construction industry, aligning with circular economy principles. The findings offer a roadmap for future innovations in sustainable construction, showcasing the potential to revolutionize concrete design while mitigating environmental impacts.

Keywords Coffee Husk Ash, Pineapple Fiber, Mechanical Properties, Natural Fiber, Material Optimization

1. Introduction

In 2023, Peru faced a significant challenge in the management of agroindustrial waste derived mainly from the massive production of coffee and pineapple. It is estimated that approximately 750 thousand tons of coffee husks and more than 575 tons of pineapple residues were generated, with a considerable fraction of these by-products being discarded without efficient utilization in 15% [1], [2]. This situation not only aggravates environmental problems such as soil, water and air pollution due to the decomposition of these residues, but also represents a loss of economic and potentially valuable resources [3]. The lack of proper management and the absence of effective recycling and reuse practices underline the urgent need to find innovative and sustainable solutions to manage these agricultural wastes, transforming an environmental problem into an opportunity for the development of technologies and practices that promote the circular economy and the conservation of natural resources [4], [5].

In response to these challenges, there has been a growing interest in harnessing these materials in the concrete sector, given the continuously increasing demand in the construction industry. The incorporation of coffee husk as ash fiber has shown promising results by significantly improving the modulus of elasticity of concrete [6],[7], while pineapple-derived fibers have demonstrated similar benefits by increasing compressive, tensile, and flexural strength [8], [9] [10]. This focus on natural fibers not only addresses the need to improve the mechanical properties of concrete, but also promotes sustainable practices by reusing agricultural wastes and reducing reliance on synthetic admixtures.

The present study focuses on exploring different proportions of coffee husk ash and pineapple fiber in concrete with f'c=210 Kg/cm^2, thoroughly evaluating their effects on mechanical properties. Despite the demonstrated potential of coffee husk ash, it is recognized that there is still much to be investigated, which opens the door to innovative discoveries in the field of concrete processing as an admixture. These admixtures can not only contribute to the reduction of greenhouse gas emissions by taking advantage of renewable materials, but could also generate new economic opportunities through the commercialization of these processed materials for various industrial and construction applications. This integrated approach not only seeks to solve pressing environmental problems, but also to foster a continuous cycle of research toward more environmentally friendly and economically viable building materials.

In this section, a comprehensive review of the existing literature on the use of coffee husk ash and pineapple fiber in the improvement of concrete properties will be carried out. Despite the increasing attention towards the use of natural fibers in construction materials, it is observed that research on the incorporation of coffee husk ash in concrete is still limited. Likewise, although studies on pineapple fiber have been documented, research on the combination of these two specific additions is scarce. This review seeks to fill that gap by providing a detailed overview of previous studies and evaluating the effectiveness of these fibers in improving the mechanical properties of concrete.

Regarding coffee husk ash, studies have shown varied results in its application in concrete. In Peru, it was observed that the incorporation of coffee husk ash with polypropylene in mixtures with strengths of f'c=210 and f'c=280 kg/cm^2 resulted in a reduction of compressive, tensile and flexural strengths by 8.94%, 15.03% and 10.89%, respectively, although the modulus of elasticity increased by 14.15% [9]. In contrast, in India, this material improved compressive, flexural and tensile strength by 28.4%, 19.35% and 1.66%, respectively [10]. On the other hand, in Ethiopia, the compressive strength decreased significantly from 35.1 MPa to 22.7 MPa with the use of coffee husk ash [11]. Given the variations in the limited research results on coffee husk ash in concrete, other uses have been explored; for example, in the Department of Civil Engineering, it has been used to stabilize soil, improving its bearing capacity up to three times and promoting sustainability through zero waste technologies [12], [13]. In Colombia, coffee husk has proven to be a viable alternative for sustainable construction, with a robust structure and a composition rich in carbon and oxygen, although internal micro-cracks were identified by Scanning Electron Microscopy [14]. In Brazil, coffee husks have been added to bricks, increasing their water absorption and insulating potential, although with a reduction in compressive strength [15]. Finally, in the Department of Civil and Construction Engineering, coffee grounds have been used as a subgrade material in roads, improving the bearing properties evaluated by unconfined compressive strength (UCS) and California bearing ratio (CBR) [16].

Regarding pineapple fiber, several international studies have explored the incorporation of pineapple fiber in concrete, highlighting its potential to improve mechanical properties and contribute to sustainability. In India, the impact of adding pineapple fiber in different proportions, from 0% to 1%, was investigated. The results indicated that concrete without fiber had a compressive strength of 35.33 N/mm^2 at 28 days. With an addition of 0.25%, the strength increased to 36.72 N/mm^2, with 0.5%, to 38.12 N/mm^2, and with 0.75%, the maximum strength of 39.92 N/mm^2 was reached. However, when 1% was used, the strength decreased slightly to 38.46 N/mm^2. In the split tensile test, the concrete without fiber showed a strength of 4.24 MPa at 28 days, which increased to 4.44 MPa with 0.10% addition. Higher fiber concentrations, such as 0.20%, 0.30%, 0.40% and 0.50%, resulted in a decrease in strength, reaching 4.19 MPa, 4.06 MPa, 3.96 MPa and 3.72 MPa, respectively [17], [18], [19].

In the Department of Civil Engineering, the application of pineapple fiber was evaluated with proportions of 0.1%, 0.2% and 0.3% in concrete. Slump tests showed values between 42 and 57 mm, indicating good workability. The incorporation of pineapple fiber improved compressive, flexural and split tensile strength, with the maximum performance achieved when using 3% pineapple fiber. This highlights the potential of fiber to improve the mechanical properties of concrete and contribute to sustainability by taking advantage of agricultural waste [20].

In Indonesia, the addition of pineapple leaf fiber was tested in self-compacting concrete with dosages of 0%, 0.2%, 0.3% and 0.4% by weight of cement. Results at 7 and 28 days showed that an optimum dosage of 0.3% increased the compressive strength to 56.28 MPa, compared to 52.14 MPa for the standard concrete. In addition, an addition of 0.4% achieved the maximum flexural strength at 28 days, reaching 7.88 MPa compared to 7.14 MPa for the control [21], [22]. Likewise, in this same country, which has an annual production of approximately 1.4 million tons, the use of its residues in concrete with pineapple fiber additions of 0%, 0.5%, 1% and 1.5% with respect to cement was investigated. The optimum dosage of 0.5% provided the highest compressive strength, reaching 31.32 MPa compared to 27.09 MPa for concrete without fiber. An improvement in tensile strength was also observed, reaching 3.13 MPa versus 2.73 MPa at 1% dosage [23].

In Kenya, where concrete is used in advanced applications, the incorporation of pineapple leaf fiber showed a significant increase in water absorption capacity from 9.82% to 47.32% with 0.2% and 1% fiber additions, respectively. The compressive strength decreased by 11.60% at 7 days with the addition of fiber. However, the splitting tensile strength increased to 51.62% with 1% fiber addition, and the flexural strength increased by 42.58% at 28 days with the same dosage [24], [25].

Based on the literature review, varied results were observed for the incorporation of coffee husk ash and pineapple fiber in concrete. Coffee husk ash showed mixed effects on the mechanical strength of concrete, with improvements in some studies and decreases in others. Pineapple fiber has shown significant potential to improve compressive, flexural and tensile strength, although with some concentrations showing suboptimal results. However, no research exploring the combined use of these two admixtures in concrete was found. Therefore, in the present investigation, concrete mixtures with different proportions of coffee husk ash (0%, 1%, 1.2%, 1.4%, 1.6%, 1.8% and 2.0%) and pineapple fiber (0%, 0.5%, 0.7%, 0.9%, 1.1%, 1.3% and 1.5%) were evaluated to determine their impact on a concrete with a base strength of f'c = 210 kg/cm ² The investigation included a total of 147 specimens: 63 cylindrical specimens for compressive strength, 63 cylindrical specimens for tensile strength and 21 prismatic beams for flexural strength.

2. Materials and Methods

This section describes the process of making concrete using coffee husk ash and pineapple fiber as admixtures. Different concrete mixes were prepared, adjusting the proportions of water, cement and aggregates for each specific combination. The coffee husk ash was obtained through a process that included drying, calcination, and sieving, while the pineapple fiber was extracted from the leaves, passing through washing, drying, and cutting stages. Subsequently, tests were carried out to evaluate compressive, flexural, and tensile strength, ensuring that all tests complied with the specifications of the Peruvian technical standard of the MTC.

2.1. Concrete

Concrete, composed of cement, water, and aggregates such as sand and gravel, is a fundamental material in construction whose quality can be improved by the incorporation of additives, such as natural or synthetic fibers [26], [27]. In this research, the impact of the addition of pineapple fibers and coffee husk ash on the mechanical properties of concrete was evaluated. Different dosages of these fibers were analyzed to determine their effect on compressive, flexural and tensile strength, with the objective of understanding how these additions influence the structural behavior of concrete.

2.2. Coffee Husk Ash

Coffee, native to tropical and subtropical regions, comes from the beans of the Coffea plant, with Coffea arabica and Coffea canephora (robusta) being the most common species [28]. Its color varies from light green in raw beans to dark brown tones after roasting. In addition to its unique flavor and aroma, coffee contains caffeine, a stimulant, and antioxidants that offer health benefits [29]. Coffee waste, such as hulls, can be recycled for compost, biofuels, or other sustainable products, promoting environmentally friendly practices and offering economic alternatives in various industries [30].

Figure 1 illustrates the process of obtaining coffee husk ash. This process starts with the collection of coffee residues (husks) (A). Subsequently, the collected husks were dried for 24 hours. After drying, the husks were calcined and then pulverised to obtain finer particles. These particles were sieved using a 200 mesh sieve to ensure uniformity. Finally, coffee husk ash (B) was obtained.

Figure 1. Coffee husk ash process

Table 1 presents the physical and mechanical properties of coffee husks, highlighting their key characteristics. Compressive strength varies between 0.5 and 2 MPa, while tensile strength ranges between 1 and 5 MPa. In addition, the modulus of elasticity is in the range of 2 to 4 GPa. These mechanical data demonstrate that coffee husks possess interesting properties that could be exploited in various applications.

Table 1. Physical and mechanical properties [15]

Density	0.5 a 0.7 g/cm^3
Moisture content	5 a 15%
Particle size	0.5 a 2mm
Compressive strength	0.5 a 2 Mpa
Tensile strength	1 a 5 MPa
Modulus of elasticity	2 a 4 Gpa

2.3. Pineapple Fiber

Pineapple is a tropical fruit with an oval or cylindrical shape, a rough and thorny skin of green and yellow tones, and a juicy and sweet yellow or white pulp. It is rich in vitamin C, manganese and vitamin B6 [31]. Native to South and Central America, it is cultivated in tropical and subtropical climates throughout the world. In addition to its food consumption, the outer leaves of the pineapple produce a strong and flexible natural fiber, valued in the textile industry for making light and shiny fabrics such as pineapple silk. It is also used in the production of paper, rope and handicraft products, supporting the local economy and promoting sustainable practices [32], [33].

Figure 2 shows the process of obtaining pineapple fibre. The process began with the collection of the leaves, as shown in image (B), followed by washing and soaking in water for 2 days to select those in good condition and facilitate handling. Subsequently, the leaves were immersed in a 2% solution of sodium hydroxide for 20 minutes and torn with a hard element to avoid excessive damage. Finally, the leaves were air-dried, tied and cut into 2 cm long fibres (A).

Figure 2. Pineapple fiber processing

Table 2 details the key physical and mechanical properties of pineapple fiber: density (1.3 - 1.5 g/cm^3), tensile strength (500 - 800 MPa), and modulus of elasticity (6 - 8 GPa). These characteristics underline its potential for advanced applications, highlighting its low water absorption and high biodegradability, crucial factors for sustainability in various industries, from composites to civil engineering.

Table 2. Physical and mechanical properties [20]

Density	1.3 a 1.5 g/cm^3
Tensile strength	500 a 800 MPa
Modulus of elasticity	6 a 8 Gpa
Water absorption	Low
Biodegradabilidad	Alta

2.4. Composition of Admixture Concrete

Table 3 summarizes the dosages used in this investigation. Water was kept constant at 208 l/m^3, as was coarse aggregate at 989 kg/m^3. Cement was 375 kg/m^3, while fine aggregate was 711 kg/m^3. The amounts of coffee husk ash (CHA) and pineapple leaf fiber (PLF) were progressively increased, starting with 6.31 kg/m^3 (CHA) and 3.01 kg/m^3 (PLF) in the first mixes, to a maximum of 2.00% and 1.50%, respectively.

2.5. Laboratory Tests

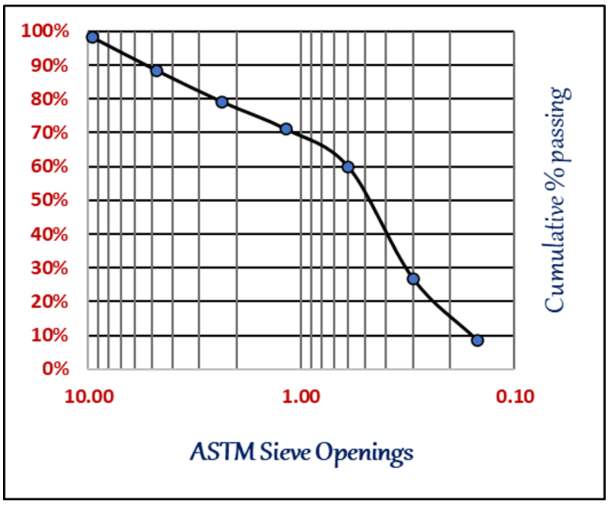
Once the dosing of the materials was completed as specified above, laboratory tests were carried out in accordance with MTC standards to evaluate the mechanical properties of the concrete. Detailed tests were carried out to determine the compressive, flexural and tensile strength in cylindrical specimens and prismatic beams. These tests were essential to analyze the impact of the coffee husk fiber and pineapple fiber additions on the behavior of the concrete under various loads. The results obtained allowed assessing the effectiveness of these admixtures in improving the capacity of concrete to resist compressive, tensile and flexural forces, which is essential for its application in structures. Finally, a general diagram summarizing the whole process and the steps followed in the research was elaborated.

2.5.1. Aggregate Particle Size

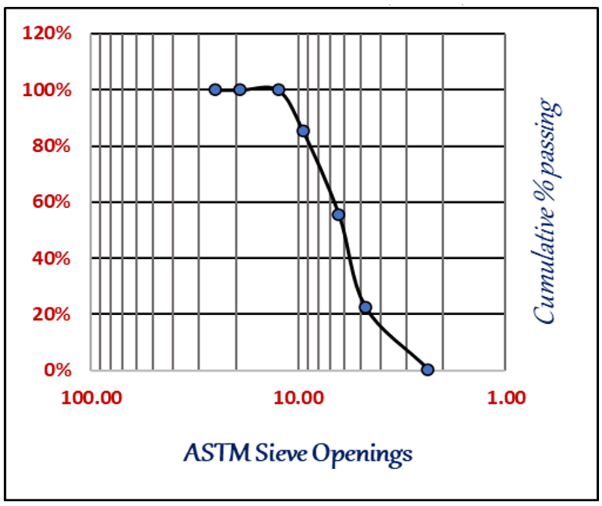
Granulometry is a crucial technique in materials engineering to analyze the particle size distribution in aggregates and soils, using methods such as sieving and laser scattering. In this test, MTC E 204 [34] was applied to evaluate both coarse and fine aggregates. It began with the preparation of a representative sample, which was dried at 110 ± 5 °C until a constant weight was reached. Next, the sample was sieved using a series of sieves with different mesh sizes: from 3/8 inches to the 100th sieve for fine aggregate, and from 2 inches to the 4th sieve for coarse aggregate, ensuring adequate agitation for an efficient separation of the particles. After sieving, the fractions retained on each sieve were weighed and the percentages of retained and passing material were calculated, which were used to construct the granulometric curves presented in Figure 3. The results obtained showed that the fine aggregate has a moisture content of 1.03%, an absorption of 1.40% and a fineness modulus of 2.7; while the coarse aggregate presented a moisture content of 0.45%, an absorption of 1.63% and a nominal maximum size of ¾" (19 mm).

Table 3. Mix design

ITEM	UNIT	Coffee husk ash and pineapple leaf fiber percentages						
		0%	1.00%CHA + 0.50%PLF	1.20%CHA + 0.70%PLF	1.40%CHA + 0.90%PLF	1.60%CHA + 1.10%PLF	1.80%CHA + 1.30%PLF	2.00%CHA + 1.50%PLF
COFFEE HUSK ASH	Kg	0.00	6.31	7.99	9.67	11.35	13.04	14.72
PINEAPPLE LEAF	Kg	0.00	3.01	3.89	4.70	5.52	6.34	7.16



A) Fine aggregate



B) Coarse aggregate

Figure 3. Granulometric Curve

2.5.2. Compressive Strength Test

The compressive strength of concrete is a fundamental parameter for determining the bearing capacity and strength of structures. In accordance with MTC E 704 [34], 63 cylindrical concrete specimens, each 15 cm in diameter and 30 cm in height, were made. These samples were prepared with varying proportions of coffee husk fibre (0%, 1%, 1.2%, 1.4%, 1.6%, 1.8% and 2.0%) and pineapple fibre (0%, 0.5%, 0.7%, 0.9%, 1.1%, 1.3% and 1.5%).

The cores were cured at a temperature of 20 ±2 ℃ and a relative humidity of 95% for 7, 14 and 28 days. After curing, the samples were tested under a constant axial load applied by a machine at a controlled strain rate of 0.25 ± 0.05 MPa/s until failure occurred. It is important to note that if the radius of the spherical head of the testing machine is smaller than the radius of the concrete specimen, the part of the loading surface extending beyond the spherical head must have a thickness not less than the difference between the radius of the sphere and the radius of the specimen. In addition, the smallest dimension of the loading surface must be at least equal to the diameter of the spherical head, as illustrated in Figure 4. The figure also highlights the different types of failures that can occur during compressive strength testing of fibre-reinforced concrete.

2.5.3. Tensile Strength Test

The tensile test is essential to evaluate the ability of concrete to withstand tensile forces, providing essential data to design safe and durable structures. In accordance with MTC E 708 [34], concrete samples were prepared and reinforced with varying proportions of pineapple and coffee husk fibres: coffee husk fibre (0%, 1%, 1.2%, 1.4%, 1.6%, 1.8% and 2.0%) and pineapple fibre (0%, 0.5%, 0.7%, 0.9%, 1.1%, 1.3% and 1.5%).

The samples were moulded into standard cylindrical specimens with a diameter of 150 mm and a length of 300 mm, resulting in a total of 63 tests. These specimens were subjected to tensile tests after curing for 7, 14 and 28 days. The tests were carried out by applying loads at rates of 50 and 100 kN per minute, which were gradually increased until the specimens reached their breaking point. To ensure accuracy, each end of the concrete cylinder was marked and aligned to remain within the same axial plane during the test. This alignment ensures uniform load distribution and reliable results, as illustrated in Figure 5.

2.5.4. Flexural Strength Test

Flexural strength is a key parameter for assessing the ability of materials, such as concrete reinforced with natural fibres like pineapple and coffee husk fibres, to resist bending forces. This test, conducted in accordance with MTC E 711 [34], used prismatic specimens. A total of 21 prismatic beam specimens were prepared with different fibre proportions: coffee husk fibre (0%, 1%, 1.2%, 1.4%, 1.6%, 1.8% and 2.0%) and pineapple fibre (0%, 0.5%, 0.7%, 0.9%, 1.1%, 1.3% and 1.5%).

The moulds were 150 mm x 150 mm in cross-section and 500 mm in length, with a clearance of three times the height. After curing for 28 days, the samples were tested using the centre-loading method. During the test, the clearance and position of the centre-loading block relative to the supporting blocks were kept constant, with a tolerance of ±1.3 mm (±0.05 in). The load was applied continuously and without interruption at a strain rate ranging from 0.9 MPa/min to 1.2 MPa/min until the specimens reached their breaking point. This procedure ensured constant contact and alignment throughout the test, as illustrated in Figure 6.

2.5.5. Flowchart of the Procedure

Figure 7 details the summary of the process carried out in our research, through a flow diagram, which included the use of materials such as cement, coarse aggregate, fine aggregate, water, and the fibers of coffee husk ash (CHA) and pineapple leaf fiber (PLF). With all the materials prepared, the appropriate separations of each fiber were made for each dosage in kg/m^3 The fiber dosages were: 0% CHA + 0% PLF, 1% CHA + 0.5% PLF, 1.2% CHA + 0.7% PLF, 1.4% CHA + 0.9% PLF, 1.6% CHA + 1.1% PLF, 1.8% CHA + 1.3% PLF, and 2% CHA + 1.5% PLF, resulting in a total of 7 different combinations. Subsequently, 84 specimens were prepared and cured for 7, 14 and 28 days. Finally, the specimens were subjected to compressive, tensile and flexural strength tests.

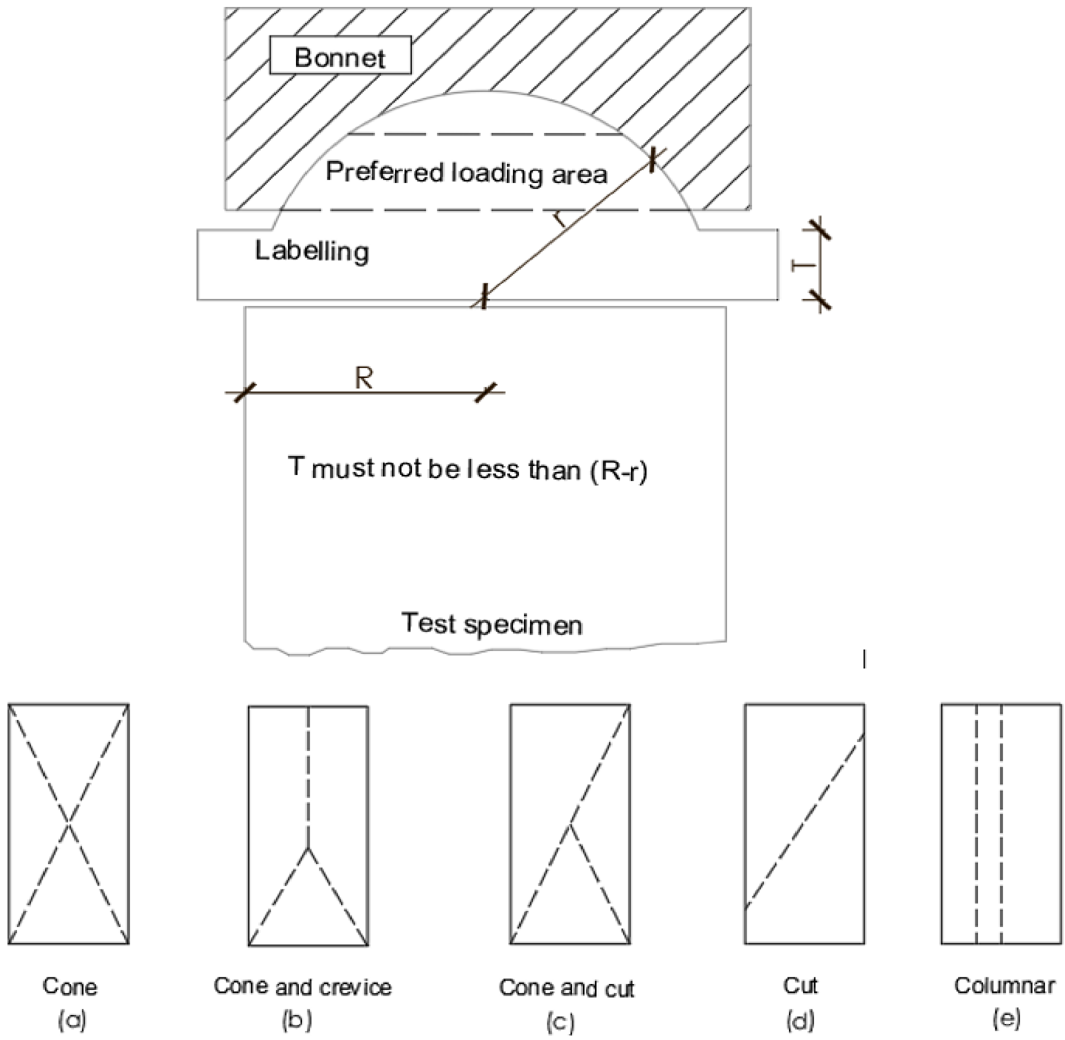


Figure 4. Concrete compressive strength test

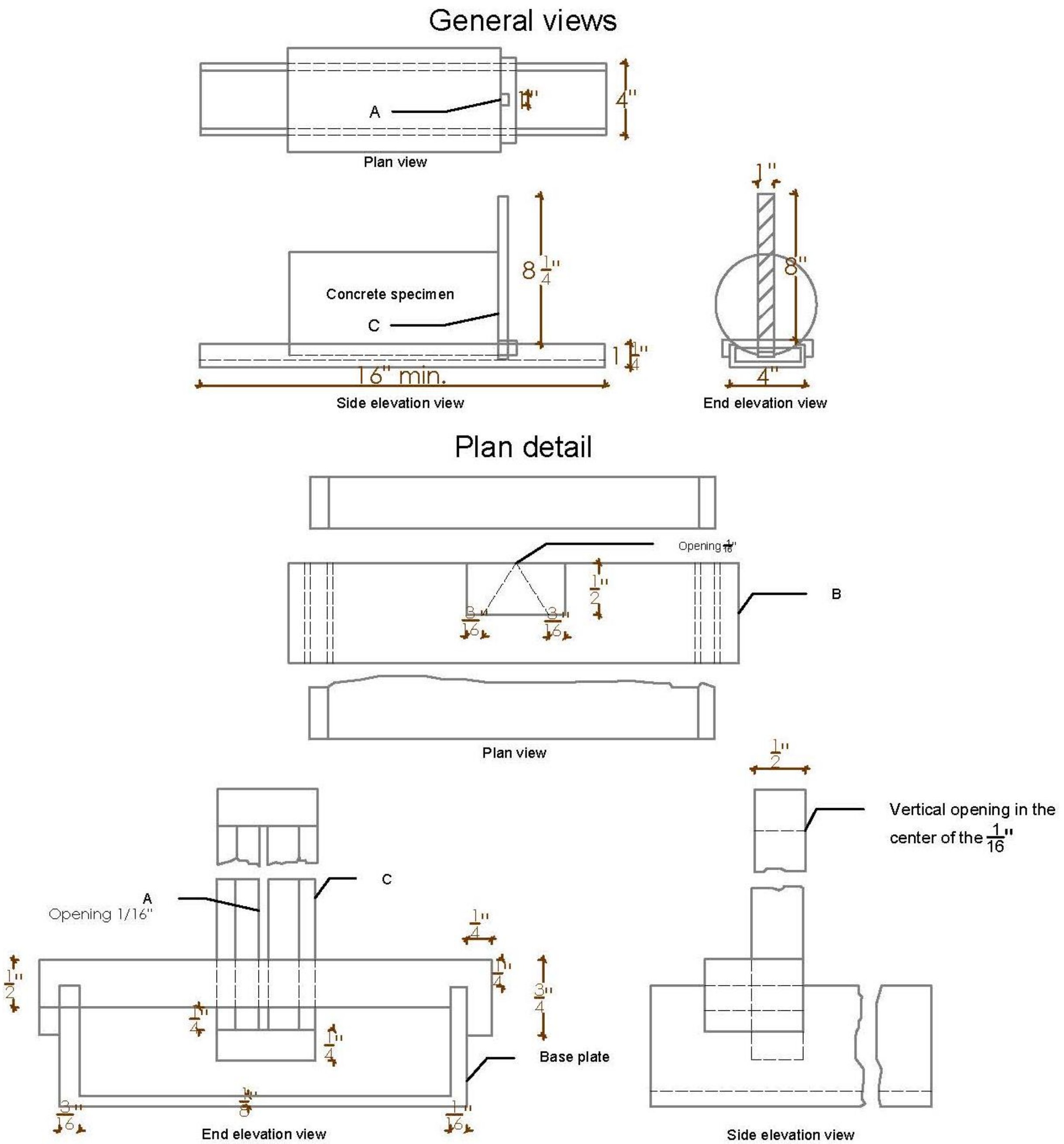


Figure 5. Concrete tensile strength test

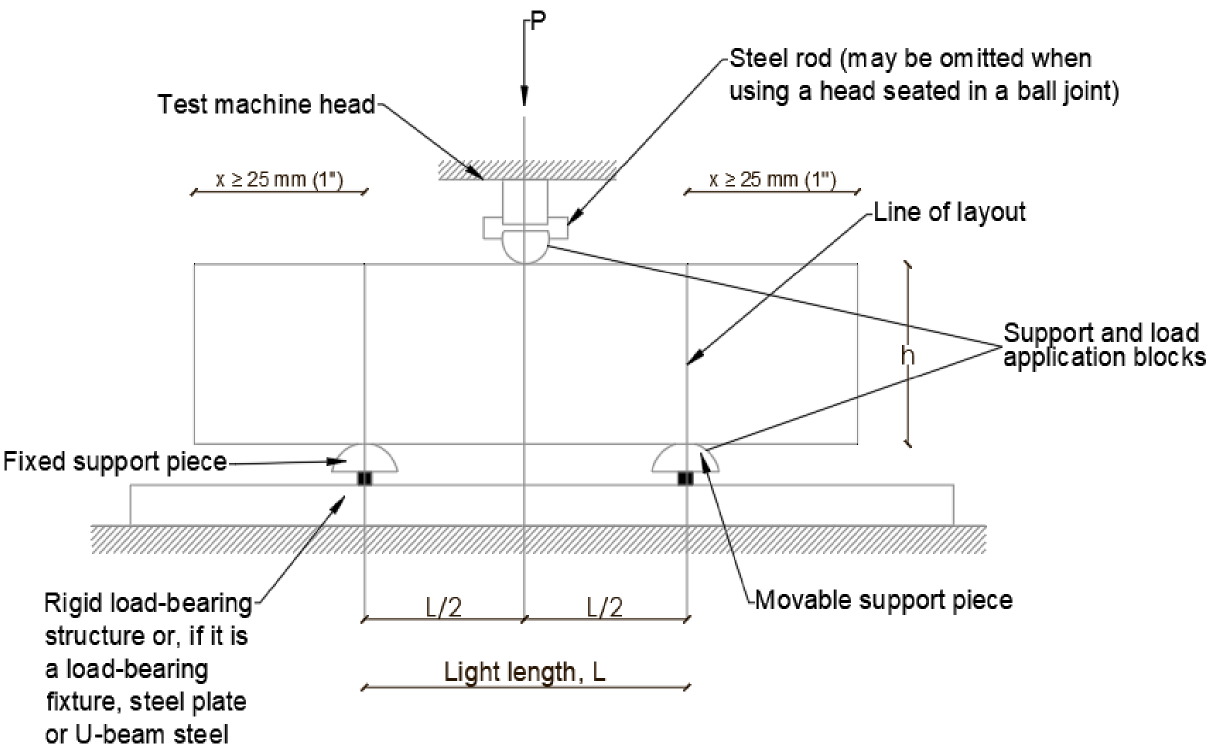


Figure 6. Concrete flexural strength test

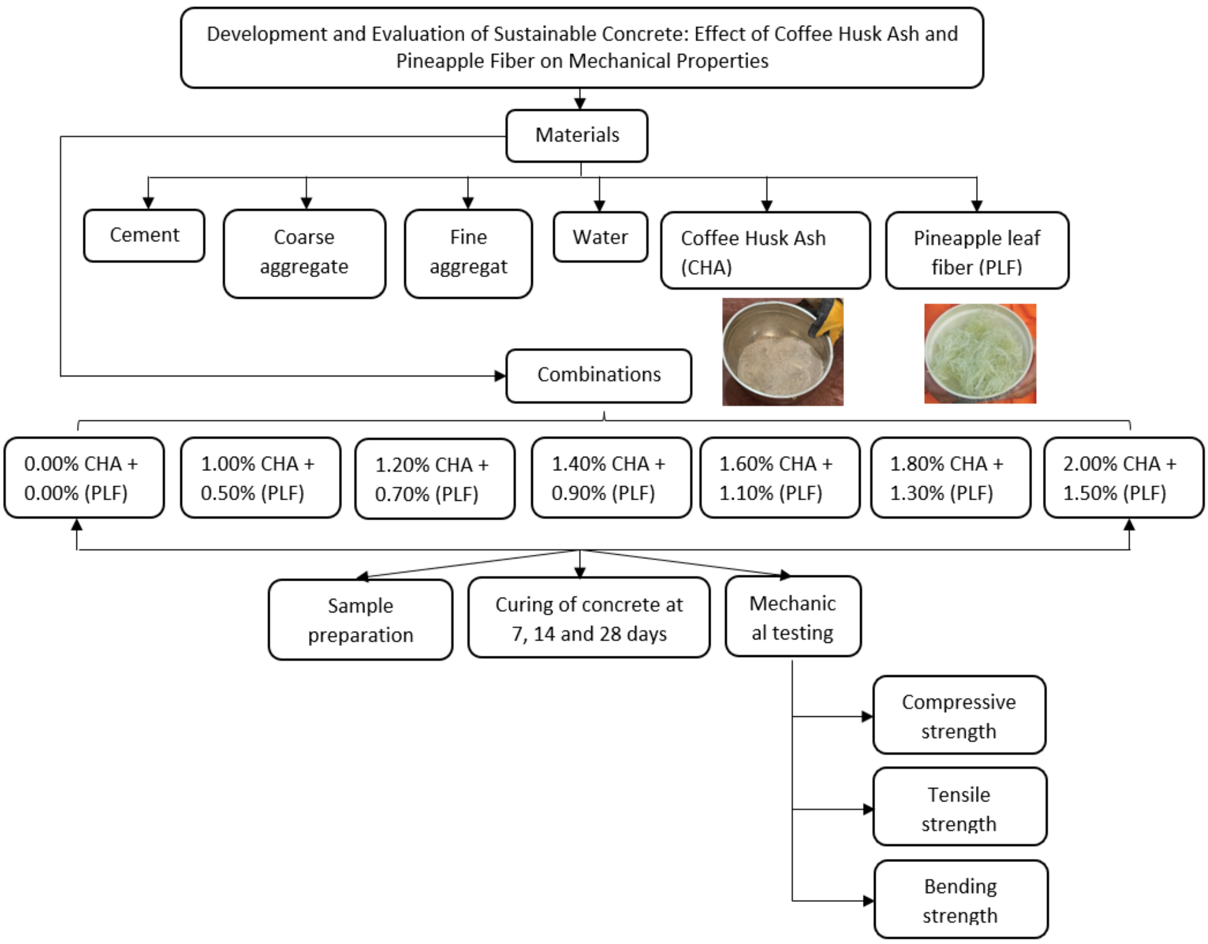


Figure 7. Flow Diagram

3. Results

This section presents the results obtained from the samples after incorporating different dosages of coffee husk ash (CHA) and pineapple leaf fiber (PLF). The combinations evaluated were: 0% CHA + 0% PLF, 1% CHA + 0.5% PLF, 1.2% CHA + 0.7% PLF, 1.4% CHA + 0.9% PLF, 1.6% CHA + 1.1% PLF, 1.8% CHA + 1.3% PLF and 2% CHA + 1.5% PLF. Compressive and tensile strength tests were carried out at 7, 14 and 28 days to evaluate the evolution of the mechanical properties of the samples with time. In addition, flexural strength was determined at 28 days to provide a complete picture of the structural performance of the specimens. These tests allowed us to analyze how the addition of these fibers affects the physical properties of the material, providing valuable data on its performance and possible applications in different contexts.

3.1. Compressive Strength

3.1.1. After 7 Days

Table 4 shows the compressive strength at 7 days, obtained as an average of three results for each dosage, in order to ensure greater accuracy in the data. This analysis allowed the mechanical performance of the different mixes to be evaluated. It should be noted that the best dosage achieved a 37.74% increase in strength, being the highest value recorded compared to the initial value, which shows a significant improvement in the properties of the material.

Table 4. Results of compressive strength at 7 days

Dosage	Break 1	Break 2	Break 3	Average
0.00% CHA + 0.00%(PLF)	179.99	171.29	175.89	175.72
1.00% CHA + 0.50%(PLF)	189.09	181.85	184.15	185.03
1.20% CHA + 0.70%(PLF)	222.34	212.58	217.19	217.37
1.40% CHA + 0.90%(PLF)	238.76	229.19	232.41	233.45
1.60% CHA + 1.10%(PLF)	244.24	238.02	243.88	242.05
1.80% CHA + 1.30%(PLF)	219.51	208.56	212.13	213.40
2.00% CHA + 1.50%(PLF)	213.31	201.13	205.79	206.74

Figure 8 shows a graph showing an increasing behaviour when using the combination of 1.6% CHA and 1.10% PLF. This increase is clearly reflected in the peak observed during the first break, with an average value close to 242.05 kg/cm ² followed by an almost constant trend in the other dosages.

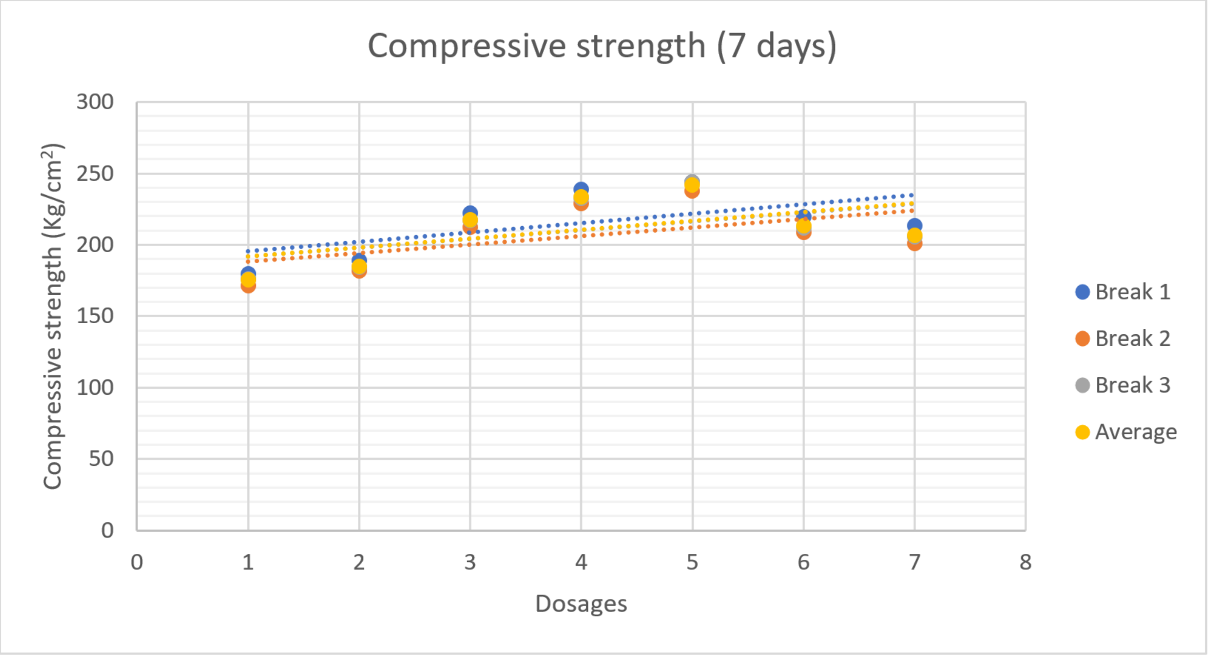


Figure 8. Compression test (7 days)

3.1.2. After 14 Days

Table 5 shows the compressive strength at 28 days for different dosages of CHA and PLF. The results show an ascending behaviour until reaching a maximum value with the combination of 1.60% CHA + 1.10% PLF, where an average of 256.70 MPa is recorded, which represents the highest strength achieved. However, by increasing the dosages beyond this point, as in 1.80% CHA + 1.30% PLF and 2.00% CHA + 1.50% PLF, the strength decreases to 216.57 MPa and 199.80 MPa, respectively. This suggests that there is an optimal limit to the proportions of CHA and PLF, as an excess can reduce the cohesion of the material and negatively affect its mechanical performance.

Figure 9 presents the 14-day cracking results, where each point on the graph represents an individual value obtained for each dosage.

3.1.3. At 28 Days

Table 6 presents the 28-day compressive strength results for different dosages of CHA and PLF, showing a progressive increase until reaching a maximum value with the dosage of 1.60% CHA + 1.10% PLF, which registers an average of 271.55 MPa, consolidating as the optimum combination. However, when increasing the dosages beyond this point, as in 1.80% CHA + 1.30% PLF and 2.00% CHA + 1.50% PLF, the strength decreases to 223.45 MPa and 208.98 MPa, respectively, suggesting that an excess of additives can negatively affect the cohesion and microstructure of the material. These results highlight the importance of proper dosage balance to maximise mechanical performance at 28 days.

Figure 10 illustrates the 28-day compressive strength results for the different dosages, visually reflecting the trends observed in Table 6. A remarkable increase in strength is highlighted, peaking at the 1.60% CHA + 1.10% PLF dosage, represented as the highest peak in the graph with an average value close to 271.55 kg/cm ²

Table 5. Compressive strength results at 14 days

Dosage	Break 1	Break 2	Break 3	Average
0.00% CHA + 0.00%(PLF)	187.51	182.12	184.23	184.62
1.00% CHA + 0.50%(PLF)	195.13	189.51	191.45	192.03
1.20% CHA + 0.70%(PLF)	225.94	215.79	219.61	220.45
1.40% CHA + 0.90%(PLF)	244.01	238.71	241.34	241.35
1.60% CHA + 1.10%(PLF)	259.86	253.49	256.76	256.70
1.80% CHA + 1.30%(PLF)	220.85	212.38	216.47	216.57
2.00% CHA + 1.50%(PLF)	203.51	196.99	198.89	199.80

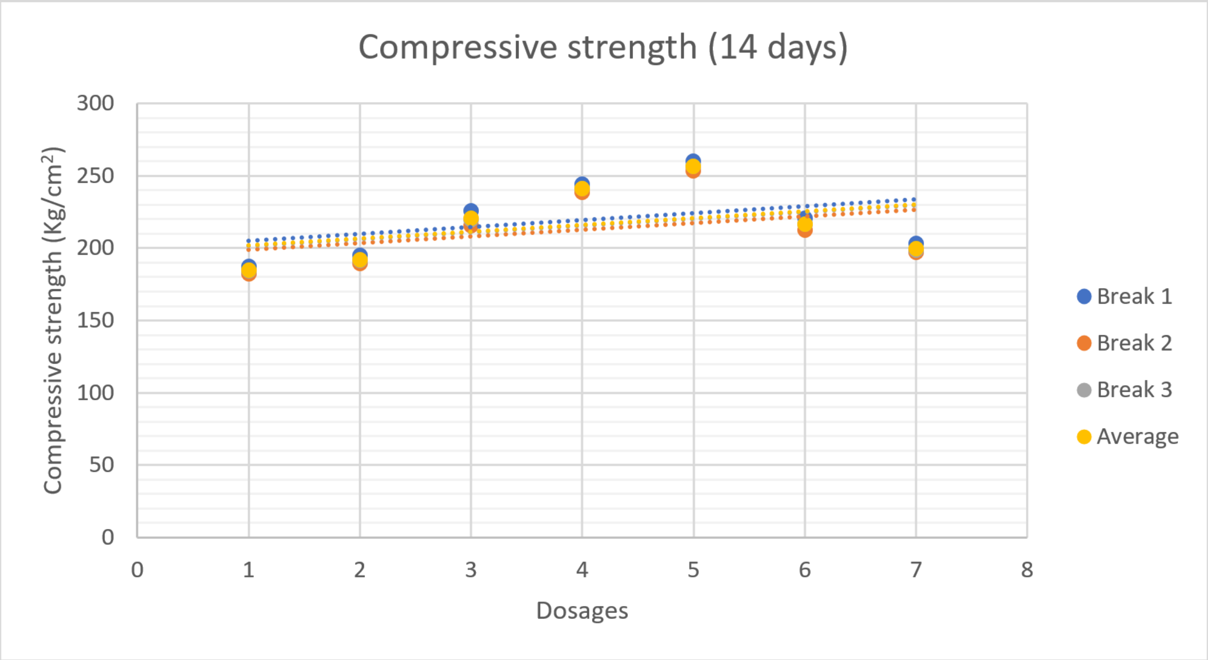


Figure 9. Compression test (14 days)

Table 6. Compressive strength results at 28 days

Dosage	Break 1	Break 2	Break 3	Average
0.00% CHA + 0.00%(PLF)	221.19	203.96	211.86	212.34
1.00% CHA + 0.50%(PLF)	225.31	221.39	223.66	223.45
1.20% CHA + 0.70%(PLF)	243.99	235.78	239.87	239.88
1.40% CHA + 0.90%(PLF)	255.54	243.15	248.67	249.12
1.60% CHA + 1.10%(PLF)	274.98	268.87	270.81	271.55
1.80% CHA + 1.30%(PLF)	226.13	218.48	225.73	223.45
2.00% CHA + 1.50%(PLF)	210.76	206.63	209.54	208.98

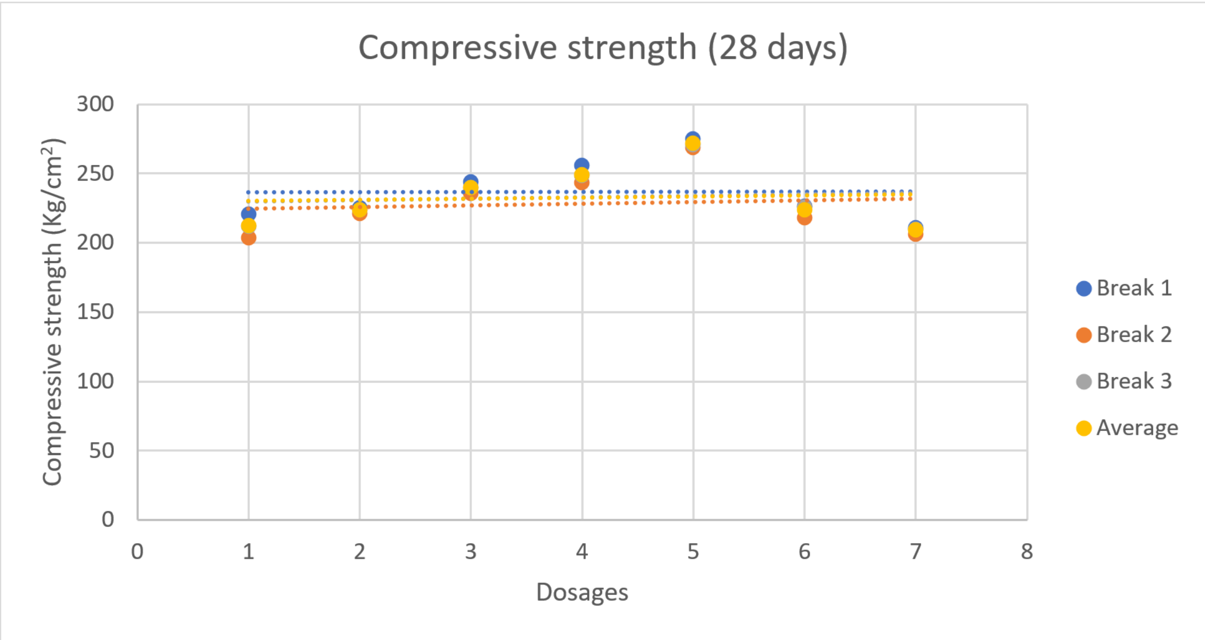


Figure 10. Compressive strength results at 28 days

Table 7. ANOVA of the compressive strength test

ANALYSIS OF VARIANCE						
Origin of variations	Sum of squares	Degrees of freedom	Mean squares	F	Probability	Critical value for F
Between groups	5971.0126	6	995.168767	77.5935851	4.7832E-06	3.86596885
Within the groups	89.7778	7	12.8254			
Total	6060.7904	13				

Table 7 presents the ANOVA analysis for the compressive strength of concrete reinforced with coffee husk ash and pineapple fibres. The results indicate that the sum of squares between groups is 5971.0126, while within groups is 89.7778, for a total of 6060.7904. With 6 degrees of freedom between groups and 7 within groups, the mean square between groups is 995.1688 and that within groups is 12.8254. The calculated F-value is 77.5936, which is significantly higher than the critical value for F, which is 3.866, with an associated probability (p-value) of 4.7832E-06, less than 0.05. These results allow us to conclude that there are statistically significant differences between the different proportions of fibres evaluated, confirming that coffee husk ash and pineapple fibres have a significant influence on the compressive strength of concrete.

3.2. Tensile Strength

3.2.1. After 7 Days

Table 8 shows the results of the tensile strength at 7 days for various dosages of CHA and PLF. A progressive increase in strength is observed until it reaches its maximum value at the 1.60% CHA + 1.10% PLF dosage, which has an average of 17.95 kg/cm^2 standing out as the strongest. However, when increasing the dosages beyond this point, as in 1.80% CHA + 1.30% PLF and 2.00% CHA + 1.50% PLF, the values decrease to 10.05 kg/cm ^{2}and 8.31 kg/cm^2 respectively. This suggests that an excess of CHA and PLF can negatively affect the tensile strength, indicating that there is an optimal dosage to obtain the best mechanical performance.

Table 8. Tensile strength results at 7 days

Dosage	Break 1	Break 2	Break 3	Average
0.00% CHA + 0.00%(PLF)	11.12	8.03	9.21	9.45
1.00% CHA + 0.50%(PLF)	11.74	7.91	10.27	9.97
1.20% CHA + 0.70%(PLF)	13.88	9.03	11.02	11.31
1.40% CHA + 0.90%(PLF)	17.31	13.09	15.47	15.29
1.60% CHA + 1.10%(PLF)	20.03	16.31	17.51	17.95
1.80% CHA + 1.30%(PLF)	12.07	8.97	9.11	10.05
2.00% CHA + 1.50%(PLF)	10.21	6.54	8.18	8.31

Figure 11 presents a box plot showing the average of the results obtained for the tensile strength of the samples analysed. It can be seen that the highest strength value is 17.95 Kg/cm^2 which represents 89.88% of the expected performance. This value is achieved with a specific dosage of 1.60% CHA and 1.10% PLF. From this point, a downward trend in strength is observed as the dosage increases. This behaviour is consistent with the data presented in the table, which shows that the higher the additive dosage, the lower the tensile strength. This suggests that there is an optimum dosage point to achieve maximum tensile strength.

3.2.2. After 14 Days

Table 9 shows the results of the tensile strength of the samples at 14 days, expressed in Kg/cm^2 for different dosages of CHA and PLF. It is observed that, with a dosage of 0.00% CHA and 0.00% PLF, the average strength is 10.18 Kg/cm^2 As the dosage of the additives is increased, the strength increases significantly, reaching its maximum value of 25.05 Kg/cm^2 at a dosage of 1.60% CHA and 1.10% PLF. However, as the dosage continues to increase, a decrease in strength is noted, with an average of 13.09 Kg/cm ^{2}at 1.80% CHA and 1.30% PLF, and 11.94 Kg/cm^2 at 2.00% CHA and 1.50% PLF. These results indicate that there is an optimum dosage point to obtain the maximum tensile strength at 14 days.

Figure 12 confirms the results with a box plot presented in Table 9, which shows the tensile strength values at 14 days. Only the average values for each dosage are plotted in this graph. It can be seen that the strength peaks at 25.05 kg/cm ^{2}at a dosage of 1.60% CHA and 1.10% PLF. As the dosage of the additives increases up to these values, the tensile strength continues to increase. However, after this point, the graph shows a downward trend, evidencing that, from certain dosages of fibre, the resistance starts to decrease. This behaviour suggests the existence of an optimum dosage point, beyond which increases in the quantity of additives do not result in improvements in strength, but in a loss of strength.

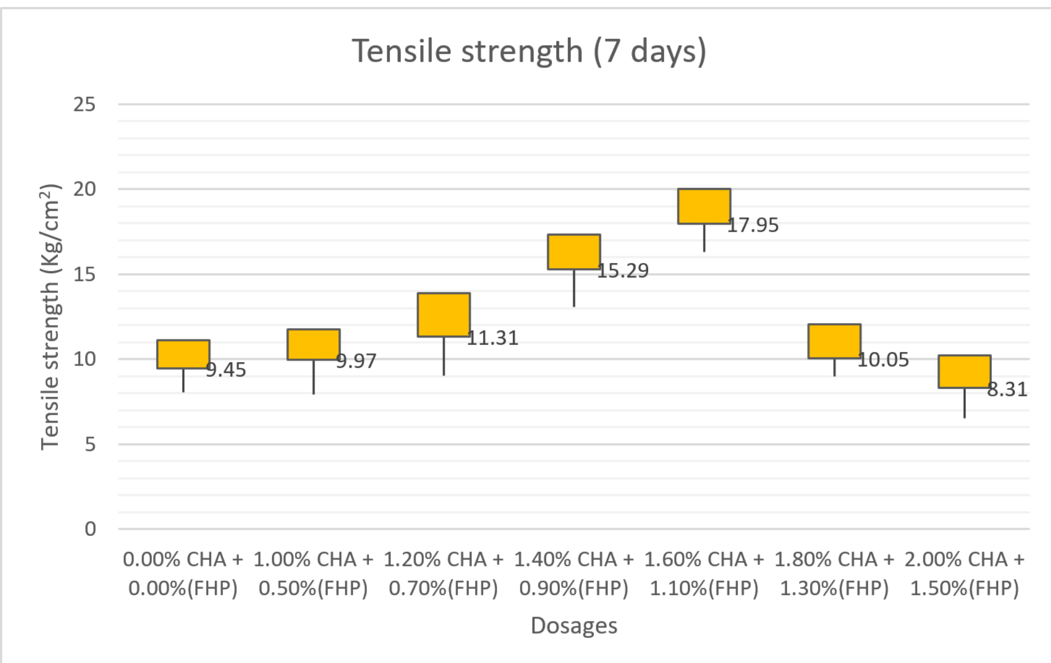


Figure 11. Tensile test (7 days)

Table 9. Tensile strength results at 14 days

Dosage	Break 1	Break 2	Break 3	Average
0.00% CHA + 0.00%(PLF)	12.18	8.11	10.26	10.18
1.00% CHA + 0.50%(PLF)	15.99	11.19	14.55	13.91
1.20% CHA + 0.70%(PLF)	20.36	14.67	17.82	17.62
1.40% CHA + 0.90%(PLF)	24.12	18.68	21.21	21.34
1.60% CHA + 1.10%(PLF)	27.11	22.99	25.05	25.05
1.80% CHA + 1.30%(PLF)	15.32	11.83	12.13	13.09
2.00% CHA + 1.50%(PLF)	14.24	9.95	11.64	11.94

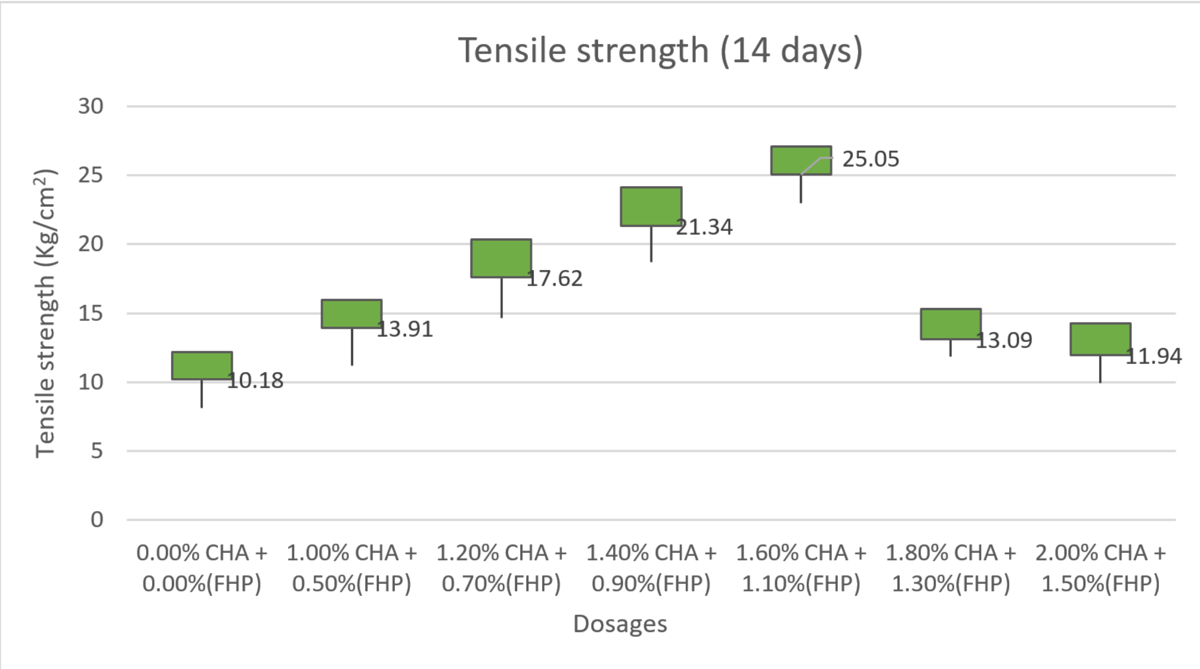


Figure 12. Tensile test (14 days)

3.2.3. At 28 Days

Table 10 shows the results of the tensile strength of the samples at 28 days, with different dosages of CHA and PLF. When analysing the data, it is observed that, with a dosage of 0.00% CHA and 0.00% PLF, the average strength is 10.91 kg/cm². As the dosage of the additives is increased, the strength increases significantly, reaching its maximum value of 32.71 Kg/cm² at a dosage of 1.60% CHA and 1.10% PLF. After this point, when the dosage is further increased, the strength starts to decrease, averaging 22.61 Kg/cm² at 1.80% CHA and 1.30% PLF, and 21.49 Kg/cm² at 2.00% CHA and 1.50% PLF. This suggests that there is an optimum dosage point (1.60% CHA and 1.10% PLF) to achieve maximum tensile strength, and that exceeding this level of additives causes a drop in the strength of the material.

Table 10. Tensile strength results at 28 days

Dosage	Break 1	Break 2	Break 3	Average
0.00% CHA + 0.00%(PLF)	13.89	8.11	10.73	10.91
1.00% CHA + 0.50%(PLF)	16.79	14.87	15.82	15.83
1.20% CHA + 0.70%(PLF)	22.31	17.54	20.31	20.05
1.40% CHA + 0.90%(PLF)	26.43	22.13	24.24	24.27
1.60% CHA + 1.10%(PLF)	34.73	30.85	32.56	32.71
1.80% CHA + 1.30%(PLF)	24.11	20.35	23.36	22.61
2.00% CHA + 1.50%(PLF)	23.35	19.27	21.86	21.49

The results presented in Table 10 are confirmed by a box plot in Figure 13, where a significant increase in tensile strength is observed. The highest value of 32.71 Kg/cm^2 is reached at a dosage of 1.60% CHA and 1.10% PLF, which represents an increase of 199.85% compared to the initial value of 10.91 Kg/cm^2, corresponding to the base dosage of 0.00% CHA and 0.00% PLF. However, after reaching this maximum, the resistance starts to decrease, stabilising at 21.49 Kg/cm^2 with a dosage of 2.00% CHA and 1.50% PLF. Despite the drop, this value is still higher than that of the base sample (10.91 Kg/cm^2), indicating that, although the strength does not continue to increase, it remains above the initial performance. This confirms that there is an optimum dosage point that maximises the tensile strength before it starts to decrease.

In Table 11（the ANOVA analysis applied to the tensile strength of concrete reinforced with coffee husk ash and pineapple fibres), the results indicate that the sum of squares between groups is 571.0594, while that within groups is 19.2921, for a total of 590.3515. With 6 degrees of freedom between groups and 7 within groups, the mean squares are 95.1766 between groups and 2.7560 within groups. The calculated F-value is 34.5341, significantly higher than the critical value of 3.866, and the associated probability (p-value) is 7.4155E-05, less than 0.05. Therefore, the null hypothesis is rejected, concluding that there are statistically significant differences between the different proportions of fibres evaluated. This confirms that coffee husk ash and pineapple fibres have a noticeable effect on the tensile strength of concrete.

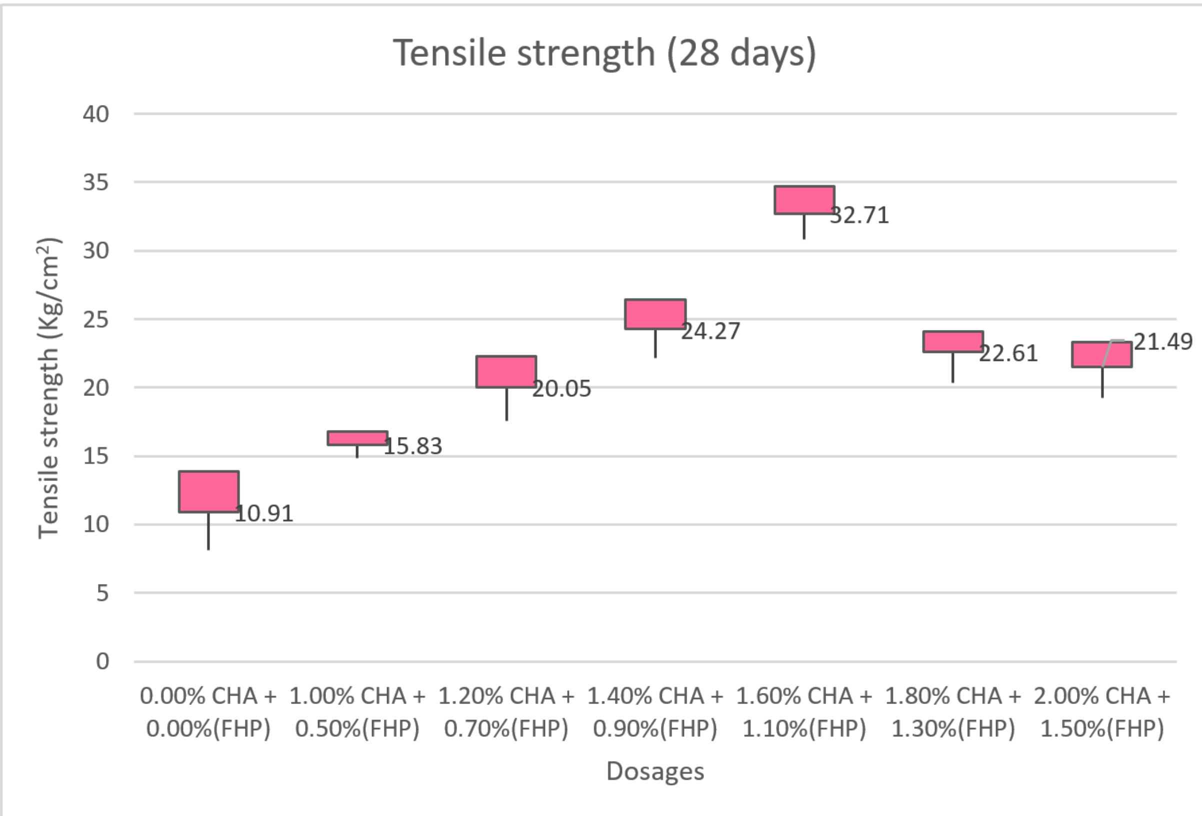


Figure 13. Tensile test (28 days)

Table 11. ANOVA of the tensile strength test

ANALYSIS OF VARIANCE						
Origin of variations	Sum of squares	Degrees of freedom	Mean squares	F	Probability	Critical value for F
Between groups	571.059386	6	95.17656429	34.5341	7.4155E-05	3.86596885
Within the groups	19.2921	7	2.756014286			
Total	590.351486	13				

3.3. Flexural Strength

3.3.1. At 28 Days

Table 12 shows the results of the flexural strength at 28 days, where a general increase in strength is observed with increasing dosage of CHA and PLF. At a dosage of 0.00% CHA and 0.00% PLF, the average strength is 41.03 kg/cm ². As the dosage increases, the strength increases significantly, reaching a maximum value of 82.81 Kg/cm ² at a dosage of 1.60% CHA and 1.10% PLF. However, after this point, the strength starts to decrease, with values of 45.18 Kg/cm ² at 1.80% CHA and 1.30% PLF, and 44.07 Kg/cm ² at 2.00% CHA and 1.50% PLF. These results suggest that the optimum dosage to obtain the highest flexural strength is around 1.60% CHA and 1.10% PLF, as the strength tends to decrease thereafter.

Table 12. Tensile strength results at 28 days

Dosage	Break 1	Break 2	Break 3	Average
0.00% CHA + 0.00%(PLF)	44.01	37.99	41.09	41.03
1.00% CHA + 0.50%(PLF)	49.38	43.43	45.22	46.01
1.20% CHA + 0.70%(PLF)	60.35	56.09	58.38	58.27
1.40% CHA + 0.90%(PLF)	72.87	68.33	70.41	70.54
1.60% CHA + 1.10%(PLF)	84.56	80.69	83.19	82.81
1.80% CHA + 1.30%(PLF)	46.17	44.21	45.15	45.18
2.00% CHA + 1.50%(PLF)	45.93	42.29	43.99	44.07

Figure 14 clearly identifies the maximum point of 82.81 Kg/cm ²corresponding to the best average obtained among the three breaks. This result highlights the effectiveness of the combination of coffee husk ash (CHA) and pineapple leaf fibre (PFF) in reinforcing the material. The improvement in the average strength is attributed to the synergy between the two components, where CHA contributes to improving the material's matrix due to its pozzolanic character, and the PLF fibres act as reinforcement, increasing the material's ability to resist stresses and reduce possible cracks.

This finding confirms that, in the optimum proportions (1.60% CHA and 1.10% PLF), the combination offers superior performance in terms of mechanical strength, consolidating itself as a viable and sustainable alternative to traditional methods. Furthermore, it is observed that when exceeding this optimum point, the strength tends to decrease, which highlights the importance of a precise balance in the dosage to avoid possible adverse effects.

In Table 13 corresponding to the ANOVA analysis, the results show that the sum of squares between groups is 3068.2691, while within groups is 16.2041, for a total of 3084.4732. With 6 degrees of freedom between groups and 7 within groups, the mean squares are 511.3782 between groups and 2.3149 within groups. The calculated F-value is 220.9100, significantly higher than the critical value of 3.866, with an associated probability (p-value) of 1.28986E-07, which is less than 0.05. Therefore, the null hypothesis is rejected, concluding that there are statistically significant differences between the evaluated groups, which confirms that the proportions of fibres used have a significant effect on the studied property.

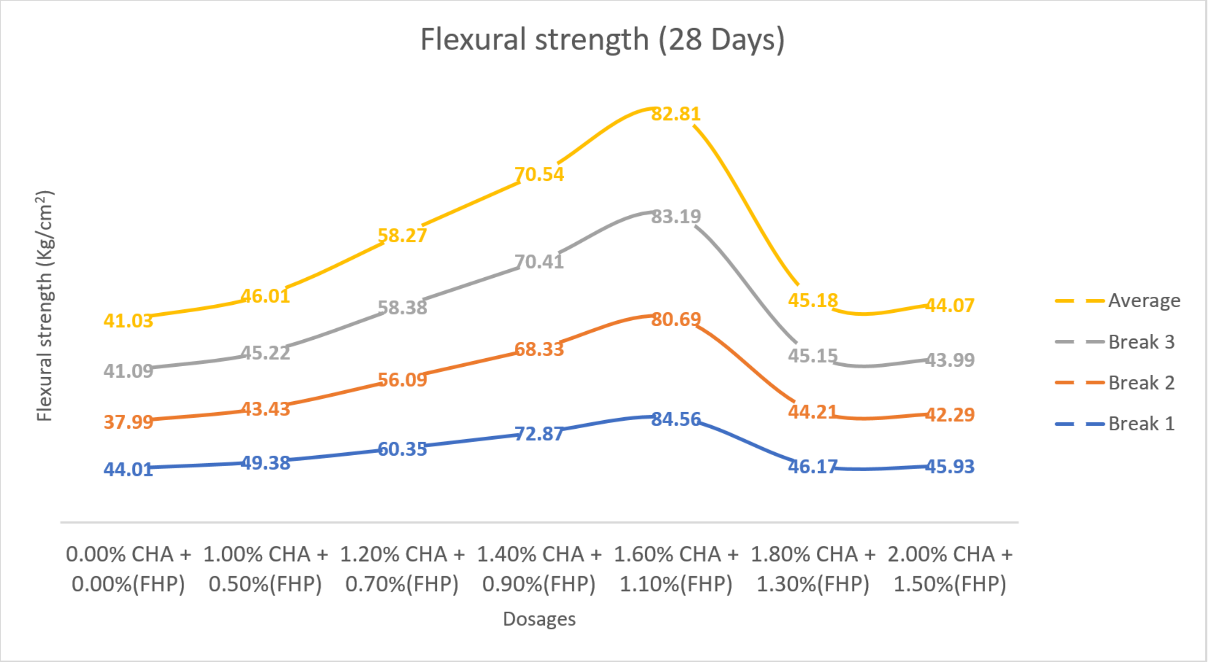


Figure 14. Flexural strength (28 days)

Table 13. ANOVA of the flexural strength test

ANALYSIS OF VARIANCE						
Origin of variations	Sum of squares	Degrees of freedom	Mean squares	F	Probability	Critical value for F
Between groups	3068.26907	6	511.3781786	220.91	1.2899E-07	3.86596885
Within the groups	16.2041	7	2.314871429			
Total	3084.47317	13				

4. Discussions

The following lines present relevant findings from previous research on the addition of natural fibers (CHA and PLF) to concrete and discuss them in relation to the results obtained in our research. This analysis allowed us to evaluate the effectiveness of natural fibers in optimizing the mechanical and structural properties of concrete, providing us with a comprehensive perspective on the impact of these additions on the durability and performance of the material.

According to J. Hadipramana, F. V. Riza, T. Amirsyah, S. N. Mokhatar, and M. Ardiansyah [35], the addition of pineapple leaf fiber improves the compressive strength of concrete over time: at 7 days, the strength increased from 31.63 to 35.40 MPa with 0.09% fiber; at 14 days, from 37.31 to 41.81 MPa with the same proportion; and at 28 days, from 54.52 to 61.19 MPa. These results coincide with our research, which shows that a combination of pineapple fiber and coffee husk ash can increase the strength to 271.55 kg/cm^2, highlighting the effectiveness of these natural fibers in improving the durability and structural capacity of concrete.

On the other hand, S. Izzatul, A. M. Sorani, N. Khazanah, A. Rahman, T. N. Hasanah, and T. Ismail [36] found that pineapple leaf fiber increased the strength of concrete, with 0.2% reaching 2.7 MPa, and 0.1% reaching 2.5 MPa, versus 2.1 MPa of the sample without fiber. However, a 0.3% ratio decreased the strength to 1.6 MPa, underscoring the sensitivity of the concrete to fiber dosage. In our research, a mixture of 1.60% coffee husk ash and 1.10% pineapple fiber showed a maximum strength of 32.71 kg/cm^2, although with a low dosage the strength decreased to 21.49 kg/cm^2 at 28 days. This highlights the potential to optimize the dosage of natural fibers for structural and sustainable applications.

M. Suhail Parathodika [37] reported that 0.1% pineapple leaf fiber increased the flexural strength to 6.14 MPa, compared to 4.66 MPa of the standard concrete. In our investigation, the combination of 1.60% coffee husk ash and 1.10% pineapple fiber achieved a flexural strength of 82.81 kg/cm^2, demonstrating that these natural fibers not only increase the strength, but also improve the durability and load-bearing capacity of concrete.

Finally, the work by A. Gedefaw, B. Worku Yifru, S. A. Endale, B. T. Habtegebreal, and M. D. Yehualaw [38], revealed that the incorporation of 20% coffee husk ash in concrete mixtures resulted in a significant decrease in compressive strength from 35.1 MPa to 22.7 MPa. However, the results obtained in the present investigation indicated a different behavior. By combining 1.60% coffee husk ash with 1.10% pineapple fiber, a maximum strength of 271.55 kg/cm^2 was achieved. This finding suggests that, although the addition of coffee husk ash in high proportions can reduce the strength of concrete, its use in moderate amounts together with pineapple fiber can significantly improve the mechanical properties of the material. This combination of admixtures is presented as a promising strategy to optimize the performance of concrete in structural applications, highlighting the importance of careful dosing to maximize the benefits of these sustainable materials.

5. Conclusions

In conclusion, the results obtained from the tests clearly show that the addition of pineapple fiber (PLF) and coffee husk ash (CHA) significantly improves the mechanical properties of the concrete. For example, the sample with 1.60% CHA and 1.10% PLF achieved a compressive strength of 271.55 kg/cm^2 at 28 days, while for tensile strength it achieved 32.71 kg/cm^2 in the same period. As for flexural strength, this same dosage showed an outstanding strength of 82.81 kg/cm^2. The optimization of fiber dosage was crucial, since higher dosages (such as 1.80% CHA and 1.30% PLF, as well as 2.00% CHA and 1.50% PLF) showed a slight decrease in strength, suggesting a critical balance between the amount of fiber added and the improvement of mechanical properties. On the other hand, the appropriate addition to improve the mechanical properties of concrete is 1.60% CHA and 1.10% PLF. These results underline the effectiveness of these fibers as admixtures to improve the structural properties of concrete, demonstrating their potential for applications where high strength and durability are required.

The results of the ANOVA analyses for the compressive, tensile and flexural strength of concrete reinforced with coffee husk ash and pineapple fibres show statistically significant differences between the different proportions of fibres used. In all cases, the calculated F-value was significantly higher than the critical value, and the associated probability (p-value) was less than 0.05, allowing the null hypothesis to be rejected. These findings confirm that both coffee husk ash and pineapple fibres have a positive impact on the mechanical properties of concrete, improving its compressive, tensile and flexural strength.

In terms of limitations, it is important to recognize that variations in the quality and characteristics of natural fibers can influence experimental results. In addition, the optimal dosage of fibers may depend on several factors such as the type of cement used, water-cement ratio and curing conditions, which may require specific adjustments for different applications and construction environments. The availability and cost of natural fibers may also affect their economic viability for large construction projects.

For future research, it would be beneficial to further explore the long-term durability of concrete reinforced with these natural fibers. Investigating how environmental conditions, including exposure to moisture and temperature cycles, affect the strength and structural integrity of concrete would be crucial to assessing its viability in various climatic conditions. In addition, studying optimization techniques in manufacturing and mix design could help maximize the benefits of pineapple and coffee husk ash in practical and commercial applications, thus promoting their wider adoption in the construction industry.

REFERENCES

[1] N. CORREO, "Junín: 750 thousand tons of coffee residues are converted into protein foods| EDICION | CORREO", Accessed: Sep. 01, 2024. [Online]. Available: https://diariocorreo.pe/edicion/huancayo/junin-750-mil-toneladas-de-residuos-de-cafe-se-convierten-en-alimentos-proteicos-noticia/

[2] "Peru exported 575 tons of pineapple for US$ 1.95 million in the first quarter of 2023." Accessed: Sep. 01, 2024. [Online]. Available: https://agraria.pe/noticias/peru-exporto-575-toneladas-de-pina-por-us-1-95-millones-en-e-31563

[3] S. Maji, D. H. Dwivedi, N. Singh, S. Kishor, and M. Gond, "Agricultural Waste: Its Impact on Environment and Management Approaches," Microorganisms for Sustainability, vol. 18, pp. 329–351, 2020, doi: 10.1007/978-981-15-1390-9_15.

[4] C. Duquennoi and J. Martinez, "European Union's policymaking on sustainable waste management and circularity in agroecosystems: The potential for innovative interactions between science and decision-making," Front Sustain Food Syst, vol. 6, p. 937802, Aug. 2022, doi: 10.3389/FSUFS.2022.937802/BIBTEX.

[5] R. Phiri, S. Mavinkere Rangappa, and S. Siengchin, "Agro-waste for renewable and sustainable green production: A review," J Clean Prod, vol. 434, p. 139989, Jan. 2024, doi: 10.1016/J.JCLEPRO.2023.139989.

[6] M. Tarekegn, K. Getachew, and G. Kenea, "Experimental Investigation of Concrete Characteristics Strength with Partial Replacement of Cement by Hybrid Coffee Husk and Sugarcane Bagasse Ash," Advances in Materials Science and Engineering, vol. 2022, no. 1, p. 5363766, Jan. 2022, doi: 10.1155/2022/5363766.

[7] A. Kitajou, J. Arai, S. Okada, T. Irawan, S. Dan, and Y. Idris, "Mechanical Properties of Foamed Concrete with Additional Pineapple Fiber and Polypropylene Fiber," J Phys Conf Ser, vol. 1198, no. 8, p. 082018, Apr. 2019, doi: 10.1088/1742-6596/1198/8/082018.

[8] S. C. Chin, M. L. Tang, N. Bakar, J. L. Che, and S. I. Doh, "Effects of Pineapple Leaf Fibre as Reinforcement in Oil Palm Shell Lightweight Concrete," Lecture Notes in Mechanical Engineering, pp. 51–60, 2023, doi: 10.1007/978-981-19-4425-3_6.

[9] A. R. G. de Azevedo, M. T. Marvila, M. L. P. Antunes, E. C. Rangel, and R. Fediuk, "Technological Perspective for Use the Natural Pineapple Fiber in Mortar to Repair Structures," Waste Biomass Valorization, vol. 12, no. 9, pp. 5131–5145, Sep. 2021, doi: 10.1007/S12649-021-01374-5/METRICS.

[10] S. P. Muñoz Pérez, M. E. Rivera Segura, Y. A. Alejandria Bustamante, and L. I. Villena Zapata, "Study of the combined effect of coffee husk ash and polypropylene fibres on the mechanical properties of concrete," Journal of Applied Research and Technology, vol. 22, no. 1, pp. 32–41, Feb. 2024, doi: 10.22201/ICAT.24486736E.2024.22.1.2131.

[11] R. P. Bhandary, A. U. Rao, P. P. Shetty, S. Blesson, and B. S. Thomas, "Application of Coffee Husk Ash as Partial Replacement of Fine Aggregate in Concrete," Sustainability 2023, Vol. 15, Page 13328, vol. 15, no. 18, p. 13328, Sep. 2023, doi: 10.3390/SU151813328.

[12] R. P. Munirwan, A. Mohd Taib, M. R. Taha, N. Abd Rahman, and M. Munirwansyah, "Utilization of coffee husk ash for soil stabilization: A systematic review," Physics and Chemistry of the Earth, Parts A/B/C, vol. 128, p. 103252, Dec. 2022, doi: 10.1016/J.PCE.2022.103252.

[13] M. K. Atahu, F. Saathoff, and A. Gebissa, "Strength and compressibility behaviors of expansive soil treated with coffee husk ash," Journal of Rock Mechanics and Geotechnical Engineering, vol. 11, no. 2, pp. 337–348, Apr. 2019, doi: 10.1016/J.JRMGE.2018.11.004.

[14] H. Y. Jaramillo, O. Vasco-Echeverri, and J. A. G. Camperos, "Characterization of the Coffee Husk: A Potential Alternative for Sustainable Construction," Civil Engineering and Architecture, vol. 11, no. 4, pp. 1902–1908, Jul. 2023, doi: 10.13189/cea.2023.110418.

[15] E. D. de Castro et al., "ANALYSIS OF THE COFFEE PEEL APPLICATION OVER THE SOIL-CEMENT BRICKS PROPERTIES," Coffee Sci, vol. 14, no. 1, p. 12, Mar. 2019, doi: 10.25186/CS.V14I1.1503.

[16] T. A. Kua, A. Arulrajah, S. Horpibulsuk, Y. J. Du, and C. Suksiripattanapong, "Engineering and environmental evaluation of spent coffee grounds stabilized with industrial by-products as a road subgrade material," Clean Technol Environ Policy, vol. 19, no. 1, pp. 63–75, Apr. 2017, doi: 10.1007/S10098-016-1188-X/METRICS.

[17] R. Roselin, "EXPERIMENTAL INVESTIGATION ON PINEAPPLE FIBRE REINFORCED CEMENT

CONCRETE," International Journal of Civil Engineering and Technology (IJCIET, vol. 9, no. 6, pp. 1479–1484, 2018, Accessed: Sep. 01, 2024. [Online]. Available: http://iaeme.com/Home/issue/IJCIET?Volume=9&Issue=6 http://iaeme.com

[18] Y. Abisha and N. Nalanth, "Pineapple fibre as an additive to self-compacting concrete," Matéria (Rio de Janeiro), vol. 28, no. 1, p. e20220315, Feb. 2023, doi: 10.1590/1517-7076-RMAT-2022-0315.

[19] Z. Amalia, M. Hasan, T. Saidi, and S. Nadia, "Bonding behavior of pineapple and silk fiber-based NFRP on strenghthened reinforced concrete beams using direct tensile test," AIP Conf Proc, vol. 2711, no. 1, May 2023, doi: 10.1063/5.0137550/2890159.

[20] S. K. Che Osmi, M. A. Zaınuddın, N. A. Misnon, S. Sojipto, and H. Husen, "Effect of Pineapple Leaf Fibre as Additional Material in Concrete Mixture," Lecture Notes in Civil Engineering, vol. 215, pp. 525–537, 2022, doi: 10.1007/978-981-16-7924-7_34.

[21] H. S. A. Hendrian, Saloma, Hanafiah, M. M. Iqbal, and I. Juliantina, "Physical and Mechanical Properties of Self-Compacting Concrete (SCC) with Pineapple Leaf Fibre and Polypropylene," J Phys Conf Ser, vol. 1783, no. 1, p. 012077, Feb. 2021, doi: 10.1088/1742-6596/1783/1/012077.

[22] S. Izzatul, A. M. Sorani, N. Khazanah, A. Rahman, T. N. Hasanah, and T. Ismail, "Study on Mechanical Properties of Concrete Contain Untreated and Treated Pineapple Leaf Fiber," Progress in Engineering Application and Technology, vol. 3, no. 1, pp. 306–316, Jun. 2022, doi: 10.30880/peat.2022.03.01.032.

[23] R. Karolina, W. Tandika, A. Hasibuan, M. A. Putra, and D. Fahreza, "Pineapple leaf fiber (PALF) waste as an alternative fiber in making concrete," J Phys Conf Ser, vol. 2193, no. 1, p. 012061, Feb. 2022, doi: 10.1088/1742-6596/2193/1/012061.

[24] K. Patrick, R. O. Onchiri, G. N. Mang'uriu, K. Patrick, R. O. Onchiri, and G. N. Mang'uriu, "Developing Suitable Proportions for the Production of Pineapple Leaf Fibers Reinforced Normal Strength Concrete," Open Journal of Civil Engineering, vol. 9, no. 3, pp. 185–194, Jul. 2019, doi: 10.4236/OJCE.2019.93013.

[25] S. C. Chin, M. L. Tang, N. Bakar, J. L. Che, and S. I. Doh, "Effects of Pineapple Leaf Fibre as Reinforcement in Oil Palm Shell Lightweight Concrete," Lecture Notes in Mechanical Engineering, pp. 51–60, 2023, doi: 10.1007/978-981-19-4425-3_6.

[26] V. W. Y. Tam, M. Soomro, and A. C. J. Evangelista, "A review of recycled aggregate in concrete applications (2000–2017)," Constr Build Mater, vol. 172, pp. 272–292, May 2018, doi: 10.1016/J.CONBUILDMAT.2018.03.240.

[27] J. Ahmad and Z. Zhou, "Mechanical Properties of Natural as well as Synthetic Fiber Reinforced Concrete: A Review," Constr Build Mater, vol. 333, p. 127353, May 2022, doi: 10.1016/J.CONBUILDMAT.2022.127353.

[28] P. Lashermes, "Coffee tree growth and environmental acclimation," pp. 39–66, Feb. 2018, doi: 10.4324/9781351114363-5.

[29] M. M. Mostafa, E. Ali, M. Gamal, and M. A. Farag, "How do coffee substitutes compare to coffee? A comprehensive review of its quality characteristics, sensory characters, phytochemicals, health benefits and safety," Food Biosci, vol. 43, p. 101290, Oct. 2021, doi: 10.1016/J.FBIO.2021.101290.

[30] L. Blinová, M. Sirotiak, A. Bartošová, and M. Soldán, "Review: Utilization of Waste From Coffee Production," Research Papers Faculty of Materials Science and Technology Slovak University of Technology, vol. 25, no. 40, pp. 91–101, Jun. 2017, doi: 10.1515/RPUT-2017-0011.

[31] J. Jain and S. Sinha, "Pineapple Leaf Fiber Polymer Composites as a Promising Tool for Sustainable, Eco-friendly Composite Material: Review," Journal of Natural Fibers, vol. 19, no. 15, pp. 10031–10052, Nov. 2022, doi: 10.1080/15440478.2021.1993478.

[32] P. Pandit, R. Pandey, K. Singha, S. Shrivastava, V. Gupta, and S. Jose, "Pineapple Leaf Fibre: Cultivation and Production," Green Energy and Technology, pp. 1–20, 2020, doi: 10.1007/978-981-15-1416-6_1.

[33] F. Vieira et al., "Coconut Waste: Discovering Sustainable Approaches to Advance a Circular Economy," Sustainability 2024, Vol. 16, Page 3066, vol. 16, no. 7, p. 3066, Apr. 2024, doi: 10.3390/SU16073066.

[34] L. C. Carlos E, "Laboratory testing manual," Ministry of Transport and Communications.

[35] J. Hadipramana, F. V. Riza, T. Amirsyah, S. N. Mokhatar, and M. Ardiansyah, "Study on Workability High Strength Concrete Containing Pineapple Leaf Fiber (PALF)," IOP Conf Ser Mater Sci Eng, vol. 1200, no. 1, p. 012006, Nov. 2021, doi: 10.1088/1757-899X/1200/1/012006.

[36] S. Izzatul, A. M. Sorani, N. Khazanah, A. Rahman, T. N. Hasanah, and T. Ismail, "Study on Mechanical Properties of Concrete Contain Untreated and Treated Pineapple Leaf Fiber," Progress in Engineering Application and Technology, vol. 3, no. 1, pp. 306–316, Jun. 2022, doi: 10.30880/peat.2022.03.01.032.

[37] M. Suhail Parathodika, "Experimental Study on Pineapple Leaf Fiber Reinforced Concrete," Int J Sci Eng Res, vol. 9, no. 2, 2019, [Online]. Available: http://www.ijser.org

[38] A. Gedefaw, B. Worku Yifru, S. A. Endale, B. T. Habtegebreal, and M. D. Yehualaw, "Experimental Investigation on the Effects of Coffee Husk Ash as Partial Replacement of Cement on Concrete Properties," Advances in Materials Science and Engineering, vol. 2022, no. 1, p. 4175460, Jan. 2022, doi: 10.1155/2022/4175460.