Civil Engineering and Architecture 13(3): 1807-1819, 2025 http://www.hrpub.org
DOI: 10.13189/cea.2025.130327

Influence of Cocoa Cob Fibre on the Durability and Performance of High-Strength Concrete

Beatriz Paola Suri Paredez, Rosmery Dalia Altamirano Huerto, Frank Anthony Bernaola Bernaola, Rando Porras Olarte*

Faculty of Civil Engineering, Continental University, Peru

Received December 6, 2024; Revised February 5, 2025; Accepted March 17, 2025

Cite This Paper in the Following Citation Styles

(a): *[1] Beatriz Paola Suri Paredez, Rosmery Dalia Altamirano Huerto, Frank Anthony Bernaola Bernaola, Rando Porras Olarte , "Influence of Cocoa Cob Fibre on the Durability and Performance of High-Strength Concrete," Civil Engineering and Architecture, Vol. 13, No. 3, pp. 1807 - 1819, 2025. DOI: 10.13189/cea.2025.130327.*

(b): *Beatriz Paola Suri Paredez, Rosmery Dalia Altamirano Huerto, Frank Anthony Bernaola Bernaola, Rando Porras Olarte (2025). Influence of Cocoa Cob Fibre on the Durability and Performance of High-Strength Concrete. Civil Engineering and Architecture, 13(3), 1807 - 1819. DOI: 10.13189/cea.2025.130327.*

Abstract The increased traffic on road infrastructure has led to higher maintenance costs, particularly for flexible pavements, while rigid pavements, despite their greater durability, require significant initial investment. In Latin America, rigid pavements are preferred for their long-term cost-effectiveness, but they can deteriorate over time. To address these challenges, this study investigates the use of cocoa pod fibers as a natural admixture in concrete to improve its mechanical, thermal, and workability properties, and ultimately enhance the durability of pavements. High-strength concrete (280 kg/cm^2) was mixed with cocoa pod fibers at dosages of 0%, 1%, 2%, 3%, and 4%. Key tests, including slump, unit weight, air content, compressive strength, and flexural strength, were conducted. The results revealed significant improvements in workability and mechanical performance, especially at dosages of 1% and 2%. These dosages provided an optimal balance between strength, flexibility, and cost-efficiency, making the concrete suitable for rigid pavement applications. Furthermore, the incorporation of 4% cocoa pod fiber resulted in a 2.32%. Thermal properties were also enhanced, with the addition of 2% cocoa pod fiber lowering the temperature by 0.7 ℃. Compressive strength increased by 15% with 1% fiber, and flexural strength peaked at 36.5 kg/cm^2 with 2% fiber. The economic analysis revealed that the incorporation of 1% fiber in the concrete generated a 2.19% increase in the unit cost, which is equivalent to an increase of approximately 11.68 soles per cubic meter compared to concrete without admixtures. This additional cost is justified by improvements in mechanical properties, such as higher compressive and flexural strength, as well as improved workability of the concrete.

Keywords High-Strength Concrete Performance, Rigid Pavements, Sustainability in Construction, Cocoa Shell Fiber

1. Introduction

In the report number 6 issued by the National Institute of Statistics and Informatics (INEI) on vehicle flow in April 2024, they indicate that there was an increase of 6.1% in light and heavy vehicles, of which 5.4% were light vehicles [1]. This represents at the same time an increase in the loads on land roads, i.e. on rigid pavement, consequently often leads to an increase in vehicular flow and results in a reduction in the durability, generating maintenance costs. Since these rigid pavements are designed on average for a durability of 20 to 30 years, but due to these increases and changes in expected flow, the durability decreases [2], [3]. In recent years, rigid pavements have gained popularity in road infrastructure due to their accessibility and ease of construction. Ensuring its proper performance and durability is essential for the economic growth of communities, which has motivated the constant search for materials that improve its properties [4], [5].

Rigid pavements, commonly used in housing estates and streets, do not require high compressive and flexural strength. However, climatic conditions and increased vehicular traffic have led to cracking, slab spalling and a reduction in pavement’s service life, negatively affecting its durability [6]. To address these challenges, additives such as natural fibres have been incorporated into concrete to reduce the carbon footprint and promote sustainability in the construction sector. These fibres have improved the physical and mechanical properties of concrete, resulting in thinner and more durable pavements [7]. The incorporation of natural fibres in concrete has been recognised as an effective strategy to improve its properties. In particular, cocoa pods, an unexploited resource that generates approximately 120 tons of cocoa shells wasted annually in Peru, represent a significant environmental problem due to the lack of proper management [8]. The scarcity of research on cocoa fibre motivated the analysis of other natural fibres to evaluate their efficiency and justify this study. For example, coconut fibre was used in reinforced concrete to improve compressive strength and its behavior in high temperatures, such as fire [9]. In addition, sisal and kenaf fibre in reinforced concrete improved tensile strength [10], [11]. In materials such as adobe, agave fibre was used to improve tensile strength [12], while treated hemp fibre increased the fracture toughness and ductility of concrete [13], and cotton fibre improved water absorption capillarity in reinforced concrete, increasing water absorption [14]. Previous research has shown that natural fibres improve various concrete properties, including compressive strength, flexural strength, tensile strength, ductility and water absorption capacity. In this context, the present study focused on the evaluation of the physical and mechanical properties of natural cocoa pod fibre in order to determine its feasibility for use in rigid pavements. Critical parameters were analysed, providing a solid technical basis for the implementation of this fibre in the improvement of road infrastructure. This research aimed not only to improve the characteristics of the rigid pavement, but also to promote sustainability through the use of an underutilised agricultural resource.

1.1. Literature Review

In this section, all research related to cocoa husk derivatives in the construction sector was reviewed, given that there has been no previous research specifically on cocoa fibre.

Researchers in the Upper East Region of Ghana conducted a comprehensive study on the use of cocoa husk ash (CPHA) as a partial replacement of cement in the production of concrete. The results indicated that the incorporation of CPHA in proportions of 12% to 18% significantly improved the mechanical properties of concrete in terms of compressive strength. Specifically, it was observed that a 6% addition of CPHA increased the tensile strength to 4.02 MPa, demonstrating its viability as a sustainable and efficient alternative in construction [15]. In parallel, in Nigeria, studies were conducted on the application of CPHA as an admixture in the manufacture of concrete blocks. These studies revealed that the inclusion of CPHA in proportions of 1% to 5% by weight of cement improved the compressive strength of the blocks by 400% compared to standard blocks. This finding underlined the effectiveness of CPHA as an additive to improve the quality and durability of local building materials [16]. In addition, the use of CPHA as an admixture in concrete was analysed at the Department of Civil Engineering in Adamawa, Nigeria. The results showed that the addition of 0.6% CPHA at 28 days increased the compressive strength by 8.20% compared to a sample without admixture. It was also observed that CPHA significantly improved the setting times, with increases in the initial and final setting times. Additionally, the use of CPHA in proportions from 0.2% to 1% improved the workability of fresh concrete, reduced drying shrinkage and decreased water absorption [17].

In Colombia, the use of cocoa shell filaments in 3D printing was investigated. The deformation, mechanical and morphological properties of the printed samples were evaluated, showing that the addition of this input significantly reduced the thermal analysis. Furthermore, an increase in tensile strength was observed when the filaments were printed at an angle of 0 ° compared to an angle of 90 °. Finally, an improvement in the deformation effect was observed, reducing it by 67% [18], [19]. In Cameroon, researchers from the School of Science analysed polyethylene terephthalate (PET) reinforced with cocoa shell powder for use in tile coverings. First, its mechanical and physical properties were evaluated. The results indicated that the addition of 20-30% cocoa shell powder in PET significantly improved tensile capacities up to 60.3 MPa, flexural capacity up to 19.5 MPa, impact strength up to 10.3 MPa and water absorption was reduced to 1.34% [20].

Due to the lack of specific research on using of cocoa fibre in construction, a review of the effectiveness of various natural fibres in rigid pavements and their behaviour in concrete was carried out. Natural fibres offer significant advantages, such as being biodegradable and from renewable resources, which makes them environmentally beneficial. In addition, their low cost and light weight make them ideal options for incorporation in rigid pavements, in line with the search for sustainable practices in infrastructure construction [21].

In Peru, researchers evaluated the incorporation of agave fibre in rigid pavements to reduce the frequency of plastic shrinkage cracks. A dosage of between 0.75% and 1.0% agave fibre was found to be effective in controlling plastic shrinkage in concrete. In addition, for pavement crack control, a dosage of 0.5% agave fibre was recommended.

These results indicate that agave fibre may be a viable solution to improve the structural integrity of rigid pavements in environments prone to plastic shrinkage [22]. In Indonesia, the application of coconut fibre in the manufacture of pavement blocks was studied. The investigation revealed that the best dosage, 0.1% coconut fibre, increased the compressive strength of the blocks to 25.39 MPa at 7 days, compared to 24.49 MPa for blocks without fibre. At 14 days, the blocks with fibre reached a flexural strength of 33 MPa, while the blocks without fibre only achieved 31.5 MPa. These results demonstrate that coconut fibre can significantly improve the mechanical properties of paving blocks [23].

In India, researchers analysed the incorporation of bamboo fibre in pavements. It was found that a 1% addition of bamboo fibre improved the compressive strength of concrete. However, as the dosage was increased to 1.5%, the compressive strength started to decrease. In contrast, the flexural strength showed a continuous improvement with increases in fibre dosage up to 1.5%. These results suggest that, while bamboo fibre can improve certain mechanical properties of concrete, its dosage must be carefully controlled to optimize the benefits [24].

Researchers at the University of Michigan investigated the incorporation of pineapple leaf fibre into pavements. The studies showed that this addition improved rutting resistance and pavement stability as assessed by Marshall and indirect tensile strength tests. These findings indicate that pineapple leaf fibre can be a beneficial addition to improve pavement performance and durability [25].

In Malaysia, the addition of kenaf fibre to porous asphalt was investigated. The results showed that a 0.3% dosage of fibre increased the permanent deformation resistance of asphalt. Furthermore, a dosage of 0.6% achieved the maximum value of resilient modulus, highlighting the effectiveness of kenaf fibre as an additive to improve the performance of porous pavements. These results suggest that kenaf fibre not only improves pavement durability, but also contributes to sustainability in construction [26].

The research reviewed demonstrates the potential of various natural fibres, such as agave, coconut, bamboo, pineapple leaves and kenaf, to improve the mechanical properties and durability of pavements. These fibres not only provide effective and sustainable solutions for construction, but also promote the use of natural resources and agricultural by-products, thus contributing to environmental sustainability. This context establishes a solid basis for exploring the potential of cocoa fibre in rigid pavements, which is why in this research we analyse the incorporation of 0, 1, 2, 3, and 4% in the addition of concrete for rigid pavements with a designed strength of 280 kg/cm^2, evaluating its performance through the tests of workability, unit weight, air content, temperature, compressive strength and flexural strength under the Manual of Materials Testing established by the Ministry of Transport and Communications (MTC) of Peru.

2. Materials and Methods

The methodology followed in this research was structured in a series of steps designed to ensure a comprehensive evaluation of cocoa pod fibre as an additive in concrete. The steps are described below:

1. Application: Cocoa fibre concrete will be applied in rigid pavements, specifically in the construction of road infrastructure such as highways and streets. This type of pavement, due to its high durability and strength, is ideal for areas that require a robust concrete surface capable of withstanding heavy loads and adverse weather conditions.
2. Selection of raw materials: The selection of materials was a critical step in ensuring the quality and consistency of the concrete mix. Cocoa pod fibre, obtained through sustainable agricultural practices, was chosen as the reinforcement material for the concrete.
3. Fibre preparation: The cocoa pod fibre was subjected to a detailed process of cleaning, drying and cutting to size. This treatment ensured that the fibres could be evenly distributed within the concrete mix, maximising their effectiveness on the material's properties. A system was also designed to incorporate different doses of cocoa pod fibre (0 %, 1 %, 2 %, 3 % and 4 %) in order to evaluate how each concentration affects the properties of the concrete.
4. Mix design: The concrete mix design incorporated fundamental materials such as cement, coarse aggregates, fine aggregates and water, adjusting their proportions according to the specific workability, strength and durability needs for the intended applications. The adjustments made to the standard mix allowed the impact of each component and fibre dosage on the final properties of the concrete to be evaluated.
5. Preparation of test samples: Fresh concrete samples were prepared by mixing the ingredients in a concrete mixer to achieve a homogeneous mix. The mixture was then used to pour samples into moulds for various tests such as slump, unit weight, air content, temperature, compressive strength and flexural strength. Special attention was paid to proper compaction and curing of the samples to ensure accurate and reliable results.
6. Evaluation of the mechanical and physical properties of the samples: The prepared samples were subjected to a series of tests to evaluate their mechanical properties (compressive strength and flexural strength), as well as their physical characteristics (workability, unit weight, air content and temperature). The tests followed standard procedures to ensure the consistency and reliability of the results.
7. Analysis of results and conclusions: The results obtained in the various tests were analysed to determine the effects of cocoa pod fibre incorporation

on the properties of the concrete. Conclusions were drawn based on the performance of different fibre dosages and recommendations for practical applications of fibre-reinforced concrete were provided.

2.1. Application

Concrete, a fundamental material in civil construction, is composed of Portland cement, sand, gravel and water, with the addition of admixtures to modify specific properties such as water and fire resistance [27], [28], [29]. The incorporation of natural fibres in its formulation has been shown to improve both its physical and mechanical properties, making concrete more adaptable to various construction needs, including building structures and pavements [30]. In this context, pavement, as an essential component of road infrastructure, is designed to withstand both dynamic and static loads generated by vehicular and pedestrian traffic. Their composition varies according to local climatic conditions, with concrete being the material of choice for rigid pavements and asphalt for flexible pavements, both of which are widely used on roads, highways and pedestrian areas [31], [32]. In addition, pavements are noted for their durability against wear and ease of maintenance, which contributes to a significant reduction in long-term operating costs [33]. In particular, rigid pavements, made of concrete, are capable of resisting compressive and bending stresses, characteristics that make them particularly suitable for moderate traffic areas, due to their long service life, high strength and minimal deformation under heavy loads [34], [35], [36]. In this study, the use of cocoa pod fibre as an additive in concrete for rigid pavements was explored, with the aim of improving the workability, strength and durability of the material, which translates into a longer service life of road infrastructures.

2.2. Raw Material Selection

Cocoa pod fiber comes from the fruit of the cocoa tree (Theobroma cacao), known for its elongated shape and its variability in size and color [37].

2.3. Fibre Processing

In this research, cocoa pod fibre from the rainforest was used to improve the physical and mechanical properties of concrete, specifically with a characteristic strength of f'c = 280 Kg/cm^2; oriented for use in rigid pavements. The study focused on testing different proportions of cocoa pod fibre, in concentrations of 0%, 1%, 2%, 3% and 4%, to evaluate its impact on the strength, durability and general behaviour of the material. The process of obtaining the fibre begins with the collection of cocoa from the rainforest, an abundant natural resource in the region. Subsequently, the fibres were ground to extract the fibres, which had variable lengths between 1 and 5 mm and a maximum diameter of 0.5 mm, thus fulfilling the necessary characteristics to be considered as plant fibres suitable for incorporation into the concrete mix. The fibres obtained were subjected to a drying process under controlled conditions to reduce their moisture content, which was essential to maintain their mechanical properties and avoid alterations in the mix. Finally, the dried fibres were incorporated into the concrete mix according to the established design proportion, seeking to improve the cohesion and strength of the concrete, especially in its ability to resist cracking and improve long-term durability, which is fundamental in the construction.

Table 1 details the amount of cocoa pod fibre used in concrete mixes, expressed in kilograms per cubic metre for different proportions, ranging from 0% to 4%. The addition starts at 3.49 kg/m^3 at 1%, gradually increasing to 6.98 kg/m^3 at 2%, 10.47 kg/m^3 at 3% and reaching 13.96 kg/m^3 at 4%.

Table 1. Amount of cocoa pod fibre

Material	Units	M01 (0%)	M02 (1%)	M03 (2%)	M04 (3%)	M05 (4%)
Cocoa fibre	Kg/m^3	0.00	3.49	6.98	10.47	13.96

These dosages allowed us to analyse how the incorporation of this material influenced the properties of the concrete, such as its strength, durability and thermal behaviour, helping to determine the optimum proportion to improve performance in different conditions.

2.4. Mix Design

Table 2 details the proportion of inputs used to reproduce the experimental procedure and ensure comparable results, specifying the amount of cement, coarse and fine aggregates, and water required to develop a concrete with a strength of 280 kg/cm^2. The formulation process followed the guidelines established by ACI 211.1-91 [38], ensuring a suitable design for the concrete mix with the addition of cocoa pod fibre. The necessary components, such as cement, coarse aggregate, fine aggregate and water, were carefully selected to meet the strength and quality standards required for the project.

Table 2. Quantity of materials for concrete mix

Material	Units	M01 (0%)	M02 (1%)	M03 (2%)	M04 (3%)	M05 (4%)
Cement	Bags	11.82	11.82	11.82	11.82	11.82
Coarse Aggregate	m^3	0.66	0.66	0.66	0.66	0.66
Fine Aggregate	m^3	0.41	0.41	0.41	0.41	0.41
Water	m^3	0.16	0.16	0.16	0.16	0.16

The granulometric analysis of the crushed stone on average, presented in Figure 1, shows the distribution of the material through different sieves, with their respective openings and masses retained on each sieve. In the table, it can be seen that the larger particles, such as those retained on the 3‘ to 1 1/2’ sieves, do not represent a significant percentage of the total mass, as the % retained is 0% on these sieves. However, as the sieve aperture decreases, the percentage retained increases, with the 1/2‘, 3/8’ and N°4 sieves showing the highest retention percentages: 23.39%, 18.49% and 35.43%, respectively. The cumulative percentage of retained material reached 100% at the bottom, with a total mass of 11,692 grams. This analysis is key to understanding the particle size distribution of the crushed stone, which directly influences the properties of the concrete, such as its strength and durability.

2.5. Sample Preparation

For the evaluation of the properties of concrete with cocoa pod fibre addition, standard procedures according to MTC E 705, MTC E 714, MTC E 706, MTC E 706, MTC E 724, MTC E 704, and MTC E 709 [39] were followed. First, fresh concrete mixtures were prepared by incorporating cocoa pod fibre in proportions of 0%, 1%, 2%, 3% and 4%. The mix was prepared homogeneously, ensuring that the components were well distributed to obtain consistent results. For the slump test, the concrete was poured into an Abrams cone in three uniform layers, which were compacted with 25 blows using a 16 mm diameter, 60 cm long steel rod. Once compacted, the cone was removed vertically in less than 5 seconds, and the difference between the initial height and the maximum height reached by the concrete surface was measured. For the evaluation of unit weight, the Washington pot method was used, where a standard-sized pot was filled with the fresh concrete, leveling its surface before recording the total weight. For the evaluation of air content, the pressure method was used, where a vessel was filled with a representative sample of compacted concrete, and then the volume of air trapped under pressure was measured. As for the temperature test, a calibrated thermometer was used and inserted into the fresh concrete to record the temperature after the reading stabilised. Finally, for the compression and flexural tests, 150 mm diameter and 300 mm high cylinders were prepared for compression, and 15 cm x 15 cm x 60 cm beams for flexure, which were cured for 7, 14 and 28 days before being tested. In total, the study included 45 cylindrical probes and 15 concrete beams, which were evaluated both in their original state and with the addition of cocoa pod fibres in the mentioned proportions.

2.6. Evaluation of Samples for Testing

The prepared samples were evaluated using the specific tests to determine their properties. In the slump test, it was monitored that the addition of cocoa pod fibre affected the workability of the concrete, recording the slump values according to the proportions of fibre added. In the unit weight test, it was questioned how the different fibre dosages influenced the density of the concrete, observing a gradual decrease in unit weight with the incorporation of more cocoa fibre. For air content, the volume of air trapped in the concrete was calculated, ensuring that the values remained within the recommended range to ensure the durability and strength of the concrete.

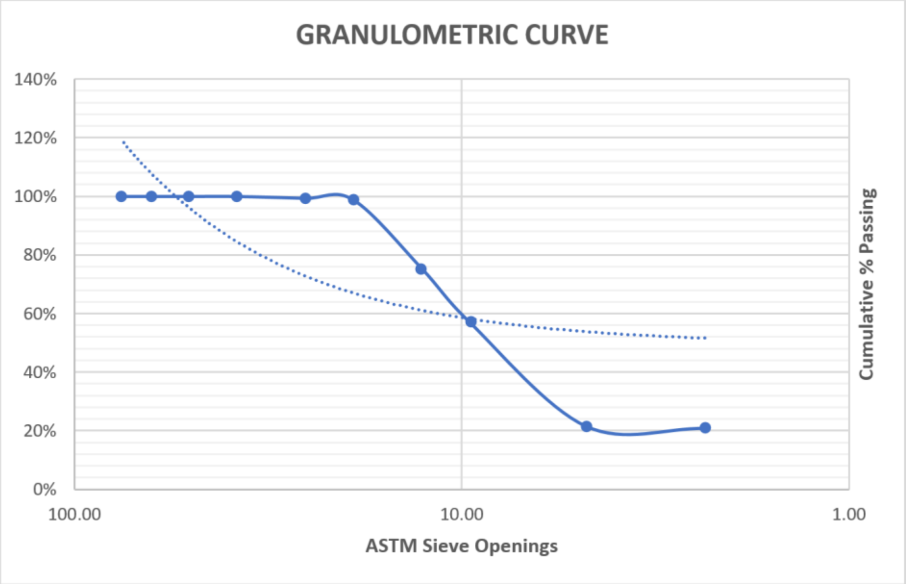


Figure 1. Granulometric Curve

The temperature test evaluated how the addition of cocoa fibre influences the thermal regulation capacity of the concrete, recording temperatures within the optimum range for curing and avoiding potential problems such as thermal cracking. Compression and flexural tests were used to evaluate the mechanical properties of the concrete, where the samples were subjected to gradual loading until the breaking point was reached. Average compressive and flexural strengths were recorded for each fibre dosage and different curing ages (7, 14 and 28 days). These tests provided key information on the structural performance of cocoa fibre concrete, allowing evaluation of its suitability for applications in columns, beams, retaining walls and other civil engineering structures requiring specific mechanical properties.

3. Results and Discussions

In this section, the performance of specimens and beams subjected to external loads is analysed during tests carried out at 7, 14 and 28 days. Different proportions (0%, 1%, 2%, 3% and 4%) of cocoa pod fibre in the concrete were evaluated, totalling 45 cylindrical specimens and 15 beams. The results of the tests at 28 days will be presented, highlighting the maximum compressive and flexural strengths achieved, which are fundamental criteria for its application in rigid pavements.

3.1. Slump Test

Figure 2 shows the results of the Abrams cone slump test used to determine the consistency of the concrete. The standard concrete had a slump of 4 inches. With the addition of 1.0% cocoa pod fibre, the slump was reduced to 3 ¾ inches. With 2.0% dosage, the slump is further reduced to 3 ½ inches. On the other hand, with 3.0% fibre, the settlement decreased to 3 ¼ inches, and with a dosage of 4%, the settlement was 3 inches.

3.2. Unit Weight

Figure 3 shows the values of the unit weight of the concrete for different proportions of cocoa pod fibres, varying from 0.00% to 4.00%. A decreasing trend in unit weight is noted as the fibre dosage increases, with values ranging from 2410 kg/m^3 in sample M01 (no fibre addition) to 2354 kg/m^3 in sample M05, which contains 4% cocoa pod fibre. This reduction suggests a greater incorporation of air into the mix, which facilitates placement and compaction of the concrete. In addition, the decrease in unit weight may lead to lighter structures, which is advantageous for reducing transportation costs and improving construction efficiency, especially in projects where large volumes of concrete need to be handled.

For example, in the research of C. Hettiarachchi and G. Thamarajah [40], the addition of coconut fibre to unit-weight concrete was analysed as a method to improve its mechanical properties. They found that an optimum addition of 2% coconut fibre reduced the unit weight from 2423.70 kg/m^3 to 2370.37 kg/m^3, resulting in a decrease of 2.20%. This finding is especially relevant for our research, where cocoa pod fibre was used instead of coconut fibre. With an addition of 4% cocoa pod fibre, a decrease in unit weight of 2.32% was obtained, suggesting similar benefits in terms of improved physical properties of the concrete.

3.3. Air Content

Figure 4 shows the air content in concrete samples with varying amounts of cocoa pod fibres. The standard concrete without fibres (M01) has an air content of 1.00%. As the fibre dosage is increased from 1.00% to 4.00%, the air content remains stable at 1.10% for samples M02 and M03 (with dosages of 1.00% and 2.00%, respectively), and then increases slightly to 1.20% for samples M04 and M05 (with dosages of 3.00% and 4.00%, respectively).

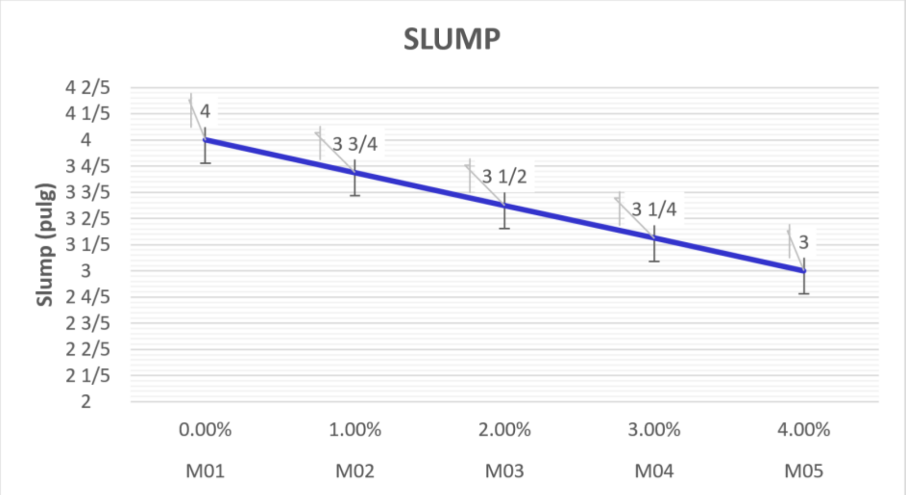


Figure 2. Workability of concrete with cocoa pod fibre addition

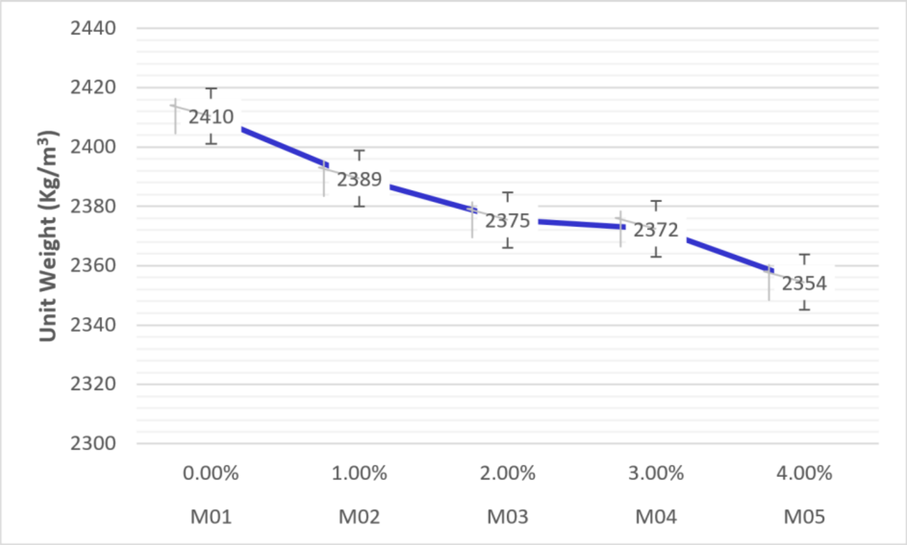


Figure 3. Unit weight of concrete with cocoa pod fibre addition

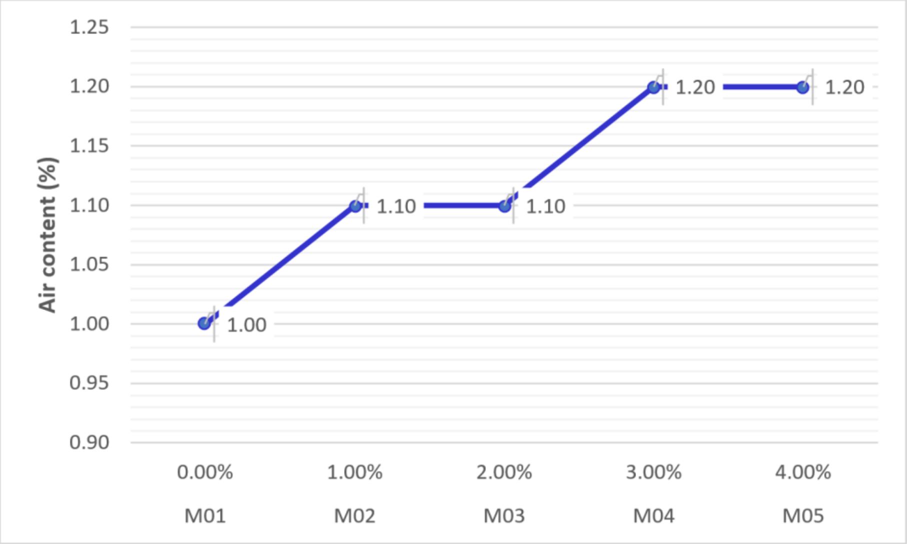


Figure 4. Air content of concrete with cocoa pod fibre addition

The study by A. R. G. de Azevedo et al. [41] showed that the addition of 5% natural acai fibre to the concrete significantly increased the air content, reaching 8.20%, compared to 7% in the standard sample. In our case, the addition of 4% cocoa pod fibre resulted in a more modest 1.2% increase in air content. Although this effect was limited, it highlights how natural fibres can influence concrete properties, especially in terms of workability and durability.

3.4. Temperature

Figure 5 shows the temperature values in degrees Celsius of the fresh concrete samples with different doses of cocoa pod fibres. The standard concrete without fibres (M01) shows a temperature of 17.90 ℃. As the fibre dosage is increased, from 1.00% to 4.00%, the temperature varies slightly between 17.20 ℃ and 18.00 ℃ for samples M02 to M04, respectively. These results suggest that the addition of cocoa pod fibres has minimal impact on concrete temperature.

Research by M. A. Mughal et al. [42], on the use of natural Kenaf fibre in asphalt concrete, showed that even small amounts of fibre affected the concrete temperature at 25 ℃ and 40 ℃, with concentrations of 0.1% and 0.3%, respectively. In comparison, our research, which incorporated 2% cocoa pod fibre, resulted in a temperature of 17.2 ℃, slightly lower than the 17.9 ℃ of the standard sample without fibre. This slight difference suggests that the addition of cocoa pod fibre could have a beneficial effect on the thermal regulation capacity of fresh concrete.

3.5. Compressive Strength

Figure 6 shows the compressive strength of the concrete, revealing significant trends with or to the cocoa pod dosage. For example, sample M02, with a 1.00% cocoa pod dosage, shows the highest compressive strength values at all curing periods (7, 14 and 28 days), with values of 252.60, 283.20 and 330.00 kg/cm^2 respectively. In contrast, sample M05, with a 4.00% cocoa pod dosage, consistently exhibits the lowest compressive strength values at the same periods, with values of 206.40, 231.10 and 285.80 Kg/cm^2 respectively. These results indicate an inverse relationship between cocoa pod dosage and the compressive strength of the concrete, where higher dosages result in a decrease in structural strength. This suggests that the addition of cocoa pods may be beneficial in improving other properties of concrete, but may compromise its compressive strength, and it is relevant to consider this effect in applications where structural strength is critical.

3.6. Bending Strength

Figure 7 shows that the flexural strength reveals significant patterns as a function of the cocoa pod additive dosage. For example, sample M03, with a 2.00% cocoa pod dosage, shows the highest flexural strength at 36.50 kg/cm^2 at 28 days of curing, while sample M01, without cocoa pod additive, shows the lowest strength at 25.01 kg/cm^2 in the same period. This indicates a general trend of increasing flexural strength as the cocoa pod dosage in the concrete increases.

However, sample M05, with a 4.00% cocoa pod dosage, shows a lower flexural strength than sample M04, which has a dosage of 3.00%. Therefore, to achieve maximum flexural strength after 28 days, the ideal amount seems to be 2% of cocoa pod fibres with or to the weight of cement. These results suggest that the addition of cocoa pods can significantly improve the flexural strength of concrete, and it is relevant to consider this optimum dosage in applications where high resistance to transverse loads is required, such as in pavement structures and structural elements subjected to bending.

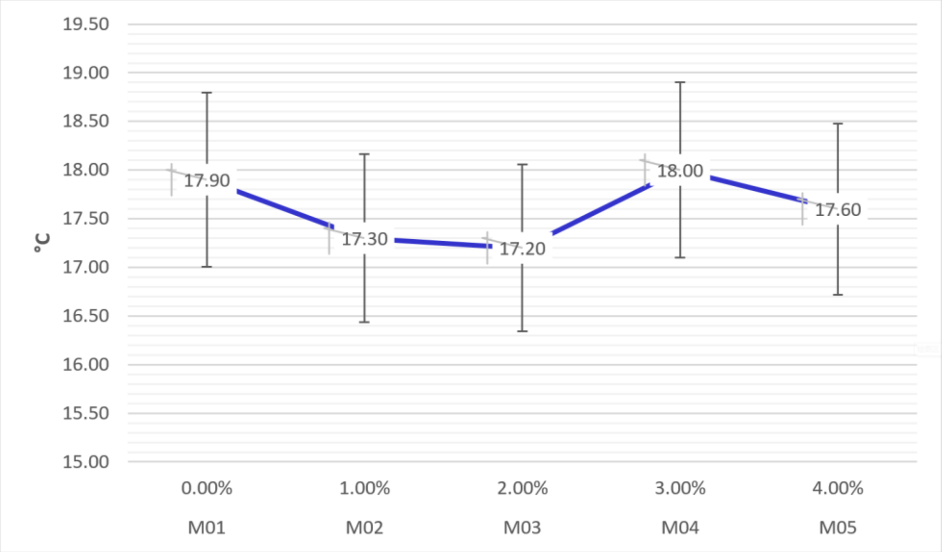
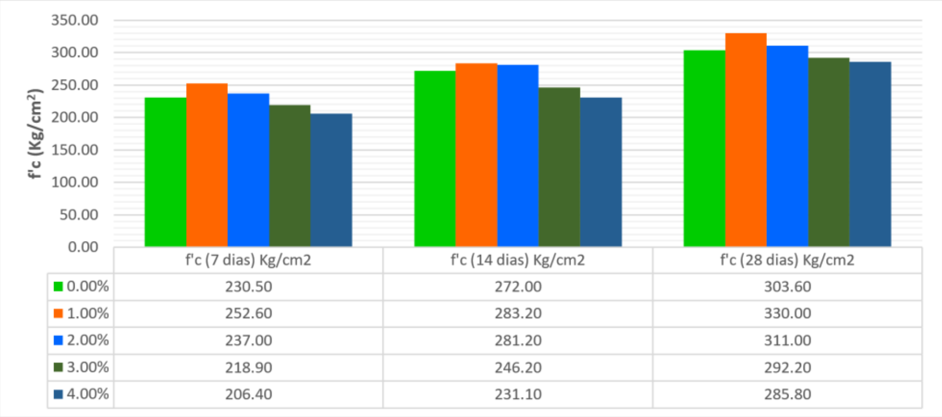


Figure 5. Temperature of the concrete with cocoa pod fibre addition



	f'c (7 dias) Kg/cm2	f'c (14 dias) Kg/cm2	f'c (28 dias) Kg/cm2
🟩 0.00%	230.50	272.00	303.60
🟧 1.00%	252.60	283.20	330.00
🟦 2.00%	237.00	281.20	311.00
🟩 3.00%	218.90	246.20	292.20
🟦 4.00%	206.40	231.10	285.80

Figure 6. Compressive strength of concrete with cocoa pod fibre addition

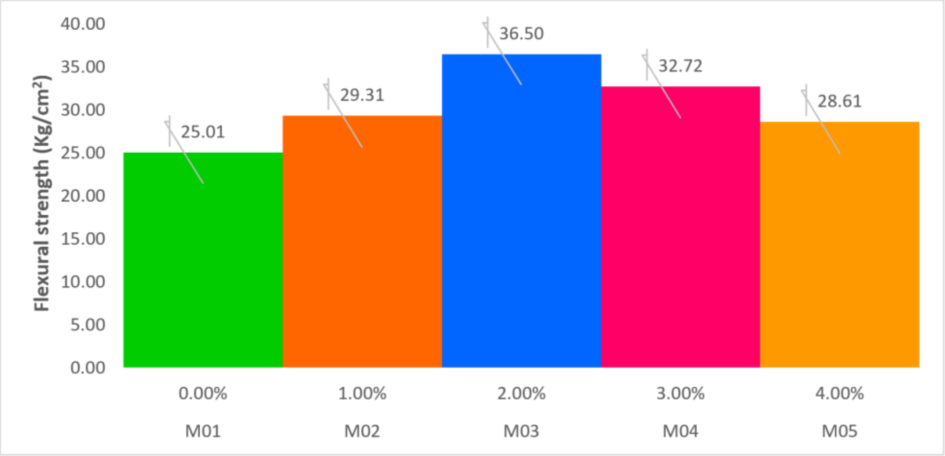


Figure 7. Flexural strength of concrete with cocoa pod fiber addition

In the study conducted by N. Dayananda et al. [43], jute fibre reinforcement in a cement concrete composite was investigated, and it was observed that the compressive strength increased to a certain extent, reaching a maximum of 44.44 N/mm ^{2} with 0.4% jute fibre content. In our research, we found significant improvements in compressive strength with the addition of 1% cocoa vanilla fibre, achieving a value of 330 kg/cm ^{2}. This result highlights how cocoa vanilla fibres can reinforce the mechanical properties of concrete, similar to the effect observed with jute fibres, but with a higher compressive strength capacity. Furthermore, in terms of flexural strength, it was observed that with a dosage of 2% cocoa pod fibre, the strength reached 36.50 kg/cm ^{2}, which also highlights a significant improvement in the mechanical properties of the concrete. These results demonstrate that the incorporation of cocoa pod fibre can be an effective option to increase both the compressive and flexural strength of concrete, which is especially useful for rigid pavements requiring high load-bearing capacity.

3.7. Unit Cost Analysis of Concrete without and with Addition and with Cocoa Pod Fiber at 1% and 2%

According to the results obtained in the physical and mechanical properties of the concrete, the addition of cocoa pod fiber showed significant improvements compared to conventional concrete, highlighting a notable increase in flexural and compressive strength with fiber concentrations of 1% and 2%. This indicates that the concrete becomes stronger and more durable with the incorporation of this fiber. Therefore, we will proceed to analyze the unit prices per cubic meter to evaluate the economic feasibility of this addition, comparing the costs of conventional concrete with those of fiber-modified concrete at the mentioned concentrations.

Table 3 shows the cost of the standard concrete, i.e., concrete without the addition of cocoa pod fiber, with a total cost of 531.63 soles per cubic meter. This amount includes labor costs, detailed as 84.70 soles for the worker and 59.80 soles for the laborer, as well as material costs, which include cement, coarse and fine aggregate, and water, all measured in cubic meters, the specific quantities of which are detailed in Table 2. In addition, an additional cost of 3% has been considered for hand tools and equipment. This calculation covers all the components necessary for the production of concrete, together with the associated labor and equipment costs.

Table 4 presents the unit cost analysis of concrete with a 1% addition of cocoa pod fiber. This analysis used the same elements as the previous tables (Table 1 and Table 2), but with some variations in labor costs due to the additional processing required for the cocoa fiber. An increase in labor cost was observed, as the fiber needed to be processed prior to use. In this regard, the quantity of the operator increased from 1.33 (according to Table 3) to 1.4 (according to Table 4), while the quantity of the laborer increased from 0.44 (Table 3) to 0.5 (Table 4). In addition, an additional piece of equipment, the chopper, whose function was to process the cocoa cob fiber, was included at a cost of 2.79 soles for a quantity of 3.49 kg/m ^{3} of fiber. As a result, the total cost of the concrete with 1% cocoa pod fiber reached 543.31 soles per cubic meter, which includes labor, materials and equipment.

On the other hand, Table 5 shows the analysis of the unit cost of concrete with an addition of 2% cocoa pod fiber. In this case, the same materials and equipment were used as in the previous analyses, but the amount of fiber used was increased to 6.98 kg/m ^{3}, which brought the unit cost of concrete with 2% cocoa pod fiber to 547.15 soles per cubic meter.

Table 3. Unit Cost Analysis of standard concrete

Conventional concrete m^3					
Efficiency: 10	m^3/dia	Direct unit cost per : m^3			**531.63**
Description	Unit	Cuadrilla	Quantity	Price S/.	Partial S/.
Labor					
Operator	hh	1.33	1.06	84.70	90.12
Customer	hh	0.44	0.35	59.80	21.05
Materials					
Portland Cement	BLS		11.82	30.00	354.60
Coarse aggregate	M3		0.66	45.00	29.70
Fine aggregate	M3		0.41	80.00	32.80
Water	L		0.16	0.16	0.03
Equipment					
Hand tools	%mo		3%	111.17	3.34

Table 4. Unit Cost Analysis of concrete with the addition of cocoa pod fiber 1%

Efficiency: 10	m^3/day	Direct unit cost per: m^3			**543.31**
Description	Unit	Cuadrilla	Quantity	Price S/.	Partial S/.
Labor					
Operator	hh	1.40	1.12	84.70	94.86
Customer	hh	0.50	0.40	59.80	23.92
Materials					
Portland Cement	BLS		11.82	30.00	354.60
Coarse aggregate	M3		0.66	45.00	29.70
Fine aggregate	M3		0.41	80.00	32.80
Water	L		0.16	0.16	0.03
Cocoa pod	KG		3.49	0.30	1.05
Equipment					
Milling	hm	1	0.8	3.49	2.79
Hand tools	%mo		3%	118.78	3.56

Table 5. Unit Cost Analysis of concrete with the addition of cocoa pod fiber 2%

Efficiency: 10	m^3/day	Direct unit cost per : m^3			**547.15**
Description	Unit	Quadrille	Quantity	Price S/.	Partial S/.
Labor					
Operator	hh	1.40	1.12	84.70	94.86
Customer	hh	0.50	0.40	59.80	23.92
Materials					
Portland Cement	bls		11.82	30.00	354.60
Coarse aggregate	m^3		0.66	45.00	29.70
Fine aggregate	m^3		0.41	80.00	32.80
Water	l		0.16	0.16	0.03
Cocoa pod	kg		6.98	0.3	2.09
equipment					
Milling	hm	1	0.8	6.98	5.58
Hand tools	%mo		3%	118.78	3.56

4. Conclusions

In conclusion, the use of natural fibers in concrete has proven to be highly beneficial in improving both its mechanical and thermal properties, making it ideal for various structural applications, especially in regions with extreme climatic conditions. In the specific case of concrete reinforced with cocoa pod fiber, an improvement in workability was observed, evidenced by a reduction in concrete slump. Without fiber, the slump was 4 inches, while with a 1% fiber dosage it was reduced to 3 ¾ inches, to 3 ½ inches with 2%, to 3 ¼ inches with 3% and finally, to 3 inches with 4%. This improvement in workability is particularly relevant for the manufacture of rigid pavements, where adequate workability is essential to ensure uniform placement and compaction, which contributes to greater durability and performance of the structure.

As for unit weight, a reduction was observed as the percentage of fiber increased. Concrete without fiber had a unit weight of 2410 kg/m^3, while with 4% fiber, this value decreased to 2354 kg/m^3. This suggests that fiber contributes to making concrete lighter, which could be useful in certain construction applications.

The air content in the concrete samples remained relatively constant between 1.00% and 1.20% with increasing fiber content, reflecting a slight increase in air capacity, especially with higher fiber dosages. This behavior may influence the durability of concrete, since higher air content may improve freeze-thaw resistance, although it may affect mechanical strength.

Regarding the temperature of the fresh concrete, variations between 17.20 ℃ and 18.00 ℃ were presented. These results suggest that the fiber does not significantly influence the thermal regulation of concrete during mixing and curing. However, its incorporation may be particularly beneficial in regions with high temperatures or hot environments, where rapid evaporation of water may increase the risk of thermal cracking. In such conditions, reducing the temperature of fresh concrete becomes crucial to mitigate this risk. In areas such as the jungle and the northern coast of Peru, for example, in cities like Iquitos (Loreto), Tarapoto (San Martin) and Piura, the use of cocoa pod fiber could play an essential role in improving the durability of concrete, helping to reduce thermal cracking associated with the high temperatures characteristic of these regions.

In terms of compressive strength, the results showed an inverse relationship with increasing fiber content. Concrete with 1% fiber achieved the highest strength values (330.00 kg/cm^2 at 28 days), while concrete with 4% fiber had the lowest values (285.80 kg/cm^2). This suggests that, although fiber improves other properties, its addition in high doses can compromise the compressive strength of concrete.

On the other hand, flexural strength showed a positive trend with the addition of cocoa pod fiber. The concrete with 2% fiber presented the highest flexural strength at 28 days, reaching 36.50 kg/cm^2, while with doses higher than 2%, the strength began to decrease. This behavior highlights the potential of the fiber to improve flexural strength, being particularly relevant for applications where resistance to transverse loads is required.

Finally, the unit cost analysis revealed that the addition of cocoa pod fiber increased the cost of the concrete. The cost per cubic meter with 1% fiber was 543.31 soles, and with 2% fiber it reached 547.15 soles. These additional costs are related to the processing of the fiber and the incorporation of specific equipment for its handling.

REFERENCES

[1] P. Abab Altamirano, J. Vera Aguilar, Jauregui Laveriano Elsa, and B. Escribano Pinaud, “Vehicle Flow by Weighing Units,” *Instituto Nacional de Estadistica e Informatica*, vol. 6, pp. 1–19, 2024, Accessed: Jul. 09, 2024. [Online]. Available: https://m.inei.gob.pe/media/MenuRecursivo/boletines/boletin_flujo_abr24.pdf

[2] C. Plati, “Sustainability factors in pavement materials, design, and preservation strategies: A literature review,” *Constr Build Mater*, vol. 211, pp. 539–555, Jun. 2019, doi: 10.1016/J.CONBUILDMAT.2019.03.242.

[3] L. F. Walubita, G. Martinez-Arguelles, R. Polo-Mendoza, S. Ick-Lee, and L. Fuentes, “Comparative Environmental Assessment of Rigid, Flexible, and Perpetual Pavements: A Case Study of Texas,” *Sustainability*, vol. 14, no. 16, p. 9983, Aug. 2022, doi: 10.3390/SU14169983.

[4] R. Polo-Mendoza *et al.*, “Environmental and economic feasibility of implementing perpetual pavements (PPs) against conventional pavements: A case study of Barranquilla city, Colombia,” *Case Studies in Construction Materials*, vol. 18, p. e02112, Jul. 2023, doi: 10.1016/J.CSCM.2023.E02112.

[5] L. Fuentes, R. Camargo, J. Arellana, C. Velosa, and G. Martinez, “Modelling pavement serviceability of urban roads using deterministic and probabilistic approaches,” *International Journal of Pavement Engineering*, vol. 22, no. 1, pp. 77–86, 2021, doi: 10.1080/10298436.2019.1577422.

[6] A. Shelar, R. Kumar, S. Shinde, and S. Patage, “Experimental Investigation on Cracks in Concrete Road Pavement,” *Mathematical Statistician and Engineering Applications*, vol. 70, no. 2, pp. 1931–1939, Dec. 2021, doi: 10.17762/MSEA.V70I2.2565.

[7] M. Osial, A. Pregowska, S. Wilczewski, W. Urbańska, and M. Giersig, “Waste Management for Green Concrete Solutions: A Concise Critical Review,” *Recycling*, vol. 7, no. 3, p. 37, Jun. 2022, doi: 10.3390/RECYCLING7030037.

[8] Mercedes Mendoza and Servindi, “Peru: Use of cocoa shells recommended in the fight against malnutrition,” INED. Accessed: Jul. 10, 2024. [Online]. Available: https://www.servindi.org/actualidad/57216

[9] G. Bamigboye, B. Ngene, O. Aladesuru, O. Mark, D. Adegoke, and K. Jolayemi, “Compressive Behaviour of Coconut Fibre (Cocos nucifera) Reinforced Concrete at Elevated Temperatures,” *Fibers*, vol. 8, no. 1, p. 5, Jan. 2020, doi: 10.3390/FIB8010005.

[10] A. Guo, Z. Sun, and J. Satyavolu, “Impact of chemical treatment on the physiochemical and mechanical properties of kenaf fibers,” *Ind Crops Prod*, vol. 141, p. 111726, Dec. 2019, doi: 10.1016/J.INDCROP.2019.111726.

[11] “Improvement of mechanical behavior of cemented soil reinforced with waste sisal fibers: an optimal selection and modification research,” *Case Studies in Construction Materials*, p. e03515, Jul. 2024, doi: 10.1016/J.CSCM.2024.E03515.

[12] M. Caballero-Caballero, F. Chinas-Castillo, J. L. Montes Bernabé, R. Alavéz-Ramirez, and M. E. Silva Rivera, “Effect on compressive and flexural strength of agave fiber reinforced adobes,” *Journal of Natural Fibers*, vol. 15, no. 4, pp. 575–585, Jul. 2018, doi: 10.1080/15440478.2017.1349709.

[13] X. Zhou, H. Saini, and G. Kastiukas, “Engineering properties of treated natural hemp fiber-reinforced concrete,” *Front Built Environ*, vol. 3, p. 268796, Jun. 2017, doi: 10.3389/FBUIL.2017.00033/BIBTEX.

[14] B. Bartulović, S. Juradin, D. Žižić, and S. Mrakovčić, “Possibility of Using Cotton Knitted Fabric Waste in Concrete,” *IOP Conf Ser Mater Sci Eng*, vol. 1203, no. 2, p. 022074, Nov. 2021, doi: 10.1088/1757-899X/1203/2/022074.

[15] P. A. Bowan, “Cocoa Pod Husk Ash as Partial Replacement of Cement in Concrete Production,” *Communications in Applied Sciences*, vol. 10, no. 0, Nov. 2021, Accessed: Jul. 11, 2024. [Online]. Available: https://infinitypress.info/index.php/cas/article/view/2049

[16] S. O. A Olawale and M. A. Tijani, “Compressive Strength of Cocoa Pod Ash Blended Sandcrete Blocks Produced in Osogbo, Nigeria,” *ANNALS of Faculty Engineering Hunedoara-International Journal of Engineering Tome*, vol. 17, no. 4, pp. 117-120, 2019.

[17] A. Vincent, E. M. And, and M. Yakubu, “Use of Cocoa Pod Husk Ash as Admixture in Concrete,” *International Journal of Engineering Research & Technology*, vol. 2, no. 11, Nov. 2013, doi: 10.17577/IJERTV2IS110716.

[18] M. A. Morales, A. Maranon, C. Hernandez, and A. Porras, “Development and Characterization of a 3D Printed Cocoa Bean Shell Filled Recycled Polypropylene for Sustainable Composites,” *Polymers*, vol. 13, no. 18, p. 3162, Sep. 2021, doi: 10.3390/POLYM13183162.

[19] G. Grillo *et al.*, “Cocoa bean shell waste valorisation; extraction from lab to pilot-scale cavitational reactors,” *Food Research International*, vol. 115, pp. 200–208, Jan. 2019, doi: 10.1016/J.FOODRES.2018.08.057.

[20] P. Nestor Djomou Djonga, A. Tom, H. Gomdje Valery, and G. Elambo Nkeng, “Mechanical Properties and Chemical Stability of Bathroom Wall Composites Manufactured from Recycle Polyethylene Terephthalate (PET) Mixed with Cocoa Hull Powder.” [Online]. Available: www.intechopen.com

[21] Y. G. Thyavihalli Girijappa, S. Mavinkere Rangappa, J. Parameswaranpillai, and S. Siengchin, “Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites: A Comprehensive Review,” *Front Mater*, vol. 6, Sep. 2019, doi: 10.3389/FMATS.2019.00226.

[22] N. A. Jorge *et al.*, “Agave Americana L fibers and control of cracks due to plastic shrinkage in rigid pavements,” in *Proceedings of the LACCEI international Multi-conference for Engineering, Education and Technology*, Latin American and Caribbean Consortium of Engineering Institutions, 2023. doi: 10.18687/laccei2023.1.1.827.

[23] R. Mudiyono and S. Sudarno, “The Influence of Coconut Fiber on the Compressive and Flexural Strength of Paving Blocks,” *Technology & Applied Science Research*, vol. 9, no. 5, pp. 4702–4705, 2019, Accessed: Jul. 12, 2024. [Online]. Available: www.etasr.com

[24] A. Mushtaq and E. S. Chalotra, “Evaluating the Impact of Using Bamboo Fibers in Pavement Design,” *International Journal of Innovative Research in Computer Science & Technology*, vol. 10, no. 5, pp. 100–106, Sep. 2022, doi: 10.55524/ijircst.2022.10.5.14.

[25] N. Hasbullah and M. E. Abdullah, “Overview of Potential Application of Pineapple Leaves Fibre (PALF) in Asphalt Mixture Focusing on Rutting Resistance,” *Recent Trends in Civil Engineering and Built Environment*, vol. 3, no. 1, pp. 853–860, 2022, doi: 10.30880/rtcebe.2022.03.01.099.

[26] K. A. Masri, N. H. Katini, A. K. Arshad, S. Shahnewaz, and R. Ferdaus, “Microstructure analysis of porous asphalt incorporating kenaf fiber in the pavement,” *Mater Today Proc*, vol. 57, pp. 1191–1195, Jan. 2022, doi: 10.1016/J.MATPR.2021.10.194.

[27] A. Surahyo, “Concrete Construction: Practical Problems and Solutions,” *Concrete Construction: Practical Problems and Solutions*, pp. 1–320, Jan. 2019, doi: 10.1007/978-3-030-10510-5/COVER.

[28] R. Dharmaraj, S. Maruthivenkatesh, K. Narayanan, M. Ramalingam, Y. Aarthi, and P. Rajalinggam, “Resilience and sturdiness of the foundry sand as a result of the partial substitution of cement and fine aggregate,” *Mater Today Proc*, vol. 68, pp. 2427–2434, Jan. 2022, doi: 10.1016/J.MATPR.2022.09.143.

[29] N. Makul, “Advanced smart concrete - A review of current progress, benefits and challenges,” *J Clean Prod*, vol. 274, p. 122899, Nov. 2020, doi: 10.1016/J.JCLEPRO.2020.122899.

[30] 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.

[31] F. Autelitano, E. Garilli, and F. Giuliani, “Criteria for the selection and design of joints for street pavements in natural stone,” *Constr Build Mater*, vol. 259, p. 119722, Oct. 2020, doi: 10.1016/J.CONBUILDMAT.2020.119722.

[32] L. R. Vásquez-Varela, F. J. García-Orozco, L. R. Vásquez-Varela, and F. J. García-Orozco, “An overview of asphalt pavement design for streets and roads,” *Revista Facultad de Ingeniería Universidad de Antioquia*, no. 98, pp. 10–26, 2021, doi: 10.17533/UDEA.REDIN.20200367.

[33] J. Wang, Q. Li, G. Song, S. Luo, and D. Ge, “Investigation

on the comprehensive durability and interface properties of coloured ultra-thin pavement overlay," *Case Studies in Construction Materials*, vol. 17, p. e01341, Dec. 2022, doi: 10.1016/J.CSCM.2022.E01341.

[34] M. I. Salama, A. Elayat, M. Reda, and G. Elsamak, "Influence of concrete type on rigid pavement behavior under static loads," *Innovative Infrastructure Solutions*, vol. 9, no. 1, pp. 1–11, Jan. 2024, doi: 10.1007/S41062-023-01316-1/FIGURES/8.

[35] Manjunatha *et al.*, "Analysis of Fixed and Variable Rigid Pavements in Comparison for Longevity, Durability and Cost-effectiveness," *E3S Web of Conferences*, vol. 507, p. 01053, Mar. 2024, doi: 10.1051/E3SCONF/202450701053.

[36] D. L. Pillay, O. B. Olalusi, and M. M. H. Mostafa, "A Review of the Engineering Properties of Concrete with Paper Mill Waste Ash – Towards Sustainable Rigid Pavement Construction," *Silicon*, vol. 13, no. 9, pp. 3191–3207, Sep. 2021, doi: 10.1007/S12633-020-00664-2/METRICS.

[37] P. Gutiérrez-Macías, V. A. Mirón-Mérida, C. O. Rodríguez-Nava, and B. E. Barragán-Huerta, "Cocoa: Beyond chocolate, a promising material for potential value-added products," *Valorization of Agri-Food Wastes and By-Products: Recent Trends, Innovations and Sustainability Challenges*, pp. 267–288, Jan. 2021, doi: 10.1016/B978-0-12-824044-1.00038-6.

[38] D. E. Dixon *et al.*, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91) Chairman, Subcommittee A," 1991.

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

[40] C. Hettiarachchi and G. Thamarajah, "Effect of Surface Modification and Fibre Content on the Mechanical Properties of Coconut Fibre Reinforced Concrete," *Adv Mat Res*, vol. 1159, pp. 78–99, Sep. 2020, doi: 10.4028/WWW.SCIENTIFIC.NET/AMR.1159.78.

[41] A. R. G. de Azevedo, M. T. Marvila, B. A. Tayeh, D. Cecchin, A. C. Pereira, and S. N. Monteiro, "Technological performance of açaí natural fibre reinforced cement-based mortars," *Journal of Building Engineering*, vol. 33, p. 101675, Jan. 2021, doi: 10.1016/J.JOBE.2020.101675.

[42] M. A. Mughal *et al.*, "Stabilizing Asphalt Concrete Using Kenaf Fibers," *Adv Sci Lett*, vol. 24, no. 6, pp. 3963–3967, Apr. 2018, doi: 10.1166/ASL.2018.11521.

[43] N. Dayananda, B. S. Keerthi Gowda, and G. L. Easwara Prasad, "A Study on Compressive Strength Attributes of Jute Fiber Reinforced Cement Concrete Composites," *IOP Conf Ser Mater Sci Eng*, vol. 376, no. 1, p. 012069, Jun. 2018, doi: 10.1088/1757-899X/376/1/012069.