PADURAKSA
Jurnal Teknik Sipil Universitas Warmadewa
ISSN Print : https://issn.brin.go.id/terbit/detail/1355981664
ISSN Online : https://issn.brin.go.id/terbit/detail/1492572000

PADURAKSA: Jurnal Teknik Sipil Universitas Warmadewa
Desember 2025, Volume 14: Nomor 2
https://doi.org/10.22225/pd.14.2.13983.312-321
Available online at https://www.ejournal.warmadewa.ac.id/index.php/paduraksa

Evaluation of basalt-based mortars incorporating local bio-fibers using the TOPSIS method: a technical, environmental, and economic assessment

Anak Agung Ngurah Dwipayana Putra[1], Putu Cinthya Pratiwi Kardita[1,*], I Made Agus Ariawan[1], Ni Ketut Ary Tubuh Harum Ningsih[1], William Steven Brian Syah[1]
[1]Civil Engineering, Udayana University, Badung, Bali, Indonesia
[*]Corresponding authors: cinthya.pratiwi@unud.ac.id

Submitted: 2 December 2025, Revised: 29 December 2025, Accepted: 31 December 2025

ABSTRACT: The construction sector in Bali still generates significant environmental waste, including from the tabas stone craft industry, which produces waste equivalent to 30% of the original stone in the form of small pieces and powder. Tabas stone is used as an ornament in traditional Balinese buildings, accounting for 50–80% of the construction material in Bali. This waste is often disposed of in rivers, reducing the wet surface area and polluting the environment. On the other hand, mortar as a binding material in construction accounts for about 30% of total building material use, making the use of environmentally friendly local materials in mortar formulations highly relevant. In 2022, out of 1.02 million tons of waste in Bali, about 70% was organic waste. Most of it came from the construction, agriculture, and handicraft sectors, such as bamboo fiber (BF), coconut fiber (CF), and pineapple leaf fiber (PLF). These materials have high cellulose content, namely bamboo powder at 53.6%, coconut husk at 43.44%, and pineapple leaves at 71.5%, which have the potential to be used as environmentally friendly mortar additives. This study aims to evaluate mortar formulations based on basalt scoria with the addition of these fibers from technical, environmental, and cost-efficiency perspectives. The TOPSIS method from the MCDM approach was used to determine the best formulation based on parameter rankings. The results showed that with the addition of 10% cellulose fibers, the compressive strength obtained was 4.137 MPa for bamboo fibers, 3.224 MPa for coconut husk fibers, and 3.923 MPa for pineapple leaf fibers. The ranking results indicate that while bamboo fiber (BF) shows the highest cost efficiency, the MS-12CCF mixture emerges as the most balanced alternative when considering technical, environmental, and economic aspects.

KEYWORDS: basalt; mortar; natural fiber; sustainable construction.

1. INTRODUCTION

The construction sector is one of the primary contributors to carbon emissions and solid waste globally (Mathur et al., 2021). One of the most widely used construction materials that contributes to waste and emissions is mortar, which serves as a binding agent in the installation of bricks, natural stone, plaster, and concrete (Kushwah et al., 2024). Mortar generally consists of sand, binding agents, and water, with sand acting as the main filler. In addition, excessive sand exploitation has negative physical, ecological, and social impacts, with an average annual extraction of around 230 million m³ from various rivers worldwide. This condition shows that conventional construction practices are still not in line with Sustainable Development Goals (SDGs) 11 and 13, which emphasize the importance of sustainable urban development and action on climate change.

In Indonesia, the construction sector is growing in line with the need for infrastructure and public facilities, but this is also accompanied by an increase in the volume of construction waste (Shooshtarian et al., 2025). One concrete example can be found in Bali, where the tabas stone craft industry produces waste amounting to around one-third of the total raw materials used. Tabas stone is widely used as a decorative element in traditional Balinese buildings, so the waste is scattered throughout the surrounding environment. Tabas stone waste, in the form of fine fragments and powder, is often dumped into rivers and open land, causing the narrowing of wet areas and environmental pollution (Astariani et al., 2023). In fact, tabas stone has a hard and rough texture that has the potential to be reused as a substitute for fine aggregates in the manufacture of environmentally friendly mortar (Almeida et al., 2025).

Several studies have attempted to develop natural-based mortar by adding natural fibers such as bamboo, coconut husks, and pineapple leaves. Adding 1-2% bamboo powder can significantly increase compressive strength (Yani et al., 2024). Research on bamboo leaf ash shows that the use of bamboo leaf ash as a partial substitute for cement can increase the compressive strength of mortar and maintain the physical properties of the mixture within standard limits, thus potentially producing a more economical and environmentally friendly material (Umoh & Odesola, 2015). Research found that at high coconut fiber contents of 1.5% and 2.0%, there was a decrease in the mechanical properties of mortar and an increase in water absorption due to uneven fiber distribution and the formation of voids in the cement matrix (Alenezi et al., 2025). In addition, research on the use of pineapple leaf fibers shows that the addition of PALF in the range of 0-7% increases the compressive strength and flexural strength of concrete (Yanti et al., 2019). Most of these studies only review technical aspects without considering the overall environmental impact or economic efficiency. Furthermore, the variation in the results obtained is highly dependent on the type of fiber, chemical treatment, and addition rate, making it difficult to determine the optimal composition. Thus, a more comprehensive evaluation approach is needed to assess the performance of mortar from various aspects simultaneously (Mohammadi & Ramezanianpour, 2023).

Based on these research gaps, this study proposes a new approach by integrating technical, environmental, and economic analyses simultaneously using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. This method allows the determination of the best mortar mix alternatives based on their distance from the ideal solution, resulting in more objective and comprehensive results (Anwar et al., 2022). This study also utilizes local resources such as bamboo fiber, coconut husks, and pineapple leaves, which are widely available in Bali, and uses basalt scoria rock as the base for the mortar mixture. This approach is expected to produce an optimal mortar formulation while supporting the principles of the circular economy and aligning with sustainability goals.

Thus, the main objective of this study is to evaluate the performance of basalt-based mortar combined with bio-local fibers using the TOPSIS method. The results of this study are expected to make a real contribution to the development of environmentally friendly construction materials that are technically efficient, economical, and ecologically sustainable, thereby supporting the application of the concept of green building.

2. METHOD

2.1. Research Location and Time

This research was conducted at the Structure and Materials Laboratory, Civil Engineering Study Program, Udayana University, Jimbaran, Bali. This laboratory is equipped with special equipment to test the technical parameters of the mortar produced. The analysis was conducted over a period of two months, from mid-May 2025 to June 2025. The main tools used in this study include 50 × 50 × 50 mm cube molds for compressive strength testing, a digital compression testing machine with a maximum capacity of 200 kN, and a digital scale with an accuracy of 0.01 g. Additionally, a manual concrete mixer, a drying oven at 105°C to control material moisture content, andstandard aggregate sieves (ASTM No. 4 and No. 100) for classifying fine aggregate particle sizes were used.

2.2. Materials and Tools

The materials used can be seen in Table 1, where natural materials are obtained from local craftsmen's waste, with details as listed in the table. The main tools used in this study include 50 × 50 × 50 mm cube molds for compressive strength testing, a digital compression testing machine with a maximum capacity of 200 kN, and a digital scale with an accuracy of 0.01 g. Additionally, a manual concrete mixer, a drying oven at 105°C to control material moisture content, and standard aggregate sieves (ASTM No. 4 and No. 100) for classifying fine aggregate particle sizes were used.

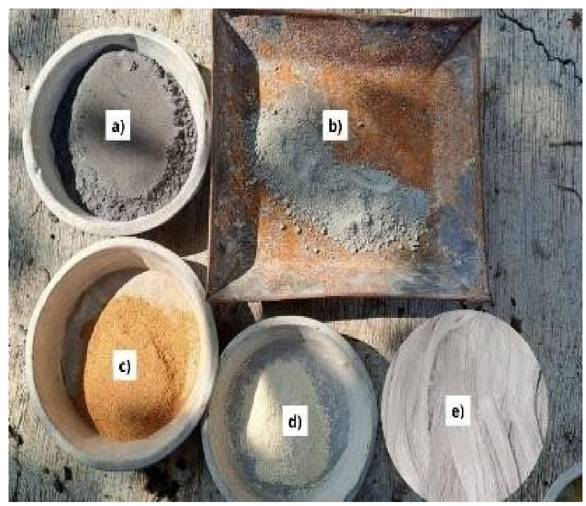

Figure 1. Raw materials used in the mortar mix: (a) tabas sand, (b) portland cement, (c) CCF, (d) BF, and (e) PLF

Table 1. Materials used in this study, their sources, utility functions, and technical specifications

Number	Materials	Source	Utility	Technical details
1	Portland cement	PT. Jimbaran Baru	Binding material	Type 1 in accordance with SNI 15-2049-2004
2	Sand	Gianyar, Bali	Fine aggregate	Size ≤ 5 mm, dried before use
3	Tabas sand (Scoria sand)	Gianyar, Bali	Partial substitution of fine aggregate	Size ≤ 5 mm, dried before use
4	Bamboo fiber (BF)	Bangli, Bali (local)	Strengthening additive	Cut to ± 20 mm, moisture content 8%
5	Coconut coir fiber (CCF)	Denpasar, Bali (local)	Strengthening additive	Without chemical treatment
6	Pineapple leaf fiber (PLF)	Gianyar, Bali	Strengthening additive	Soak in 2% tannic acid before mixing
7	Superplasticizer (SP)	Denpasar, Bali	Strengthening additive	Type F (ASTM C494)
8	Water	PDAM	Solvent	In accordance with SNI 03-2847-2002

2.3. Mix Design

The mix design follows SNI 06-6867-2002 for specifications for fly ash and other pozzolans for use with lime, where more complete calculations can be seen in Table 2.

Figure 2. Mortar cube specimens: (a) water curing, (b) fresh mortar in molds.

2.4. Data Collection Methods

Each mortar mix variation was prepared in three 50 × 50 × 50 mm cube samples to ensure representative results. The curing process was carried out for 28 days in laboratory humidity conditions with an average temperature of 25 ± 2 °C. Compressive strength testing was performed using a 200 kN digital compression testing machine in accordance with ASTM C109/C109M-16a, while density and porosity testing followed ASTM C642-13.

2.5. Tested Parameters

2.5.1 Technical testing

Compressive strength testing is one of the main tests that is crucial for design purposes and structural integrity evaluation (Indelicato & Paggi, 2008). Compressive strength is defined as the magnitude of force (F) applied continuously to a surface area (A) until the test specimen cracks or breaks. The compressive strength value is calculated in Equation 1.

$$f_m(\text{MPa}) = \frac{P\ (\text{N})}{A\ (\text{mm}^2)} \quad (1)$$

where f_m is mortar compressive strength; P is the maximum load when the mortar test specimen breaks; A is the cross-sectional area of the test object.

Density (ρ) testing is conducted when the test object is in a dry condition in open air (Wu et al., 2023). The mass of the object is weighed first, then its length, width, and thickness are measured to obtain the total volume. The density value is calculated using Equation 2.

$$\rho\ (\text{g/cm}^3) = \frac{m\ (\text{g})}{V\ (\text{cm}^3)} \quad (2)$$

where ρ is density; m is test object mass; V is volume.

The porosity testing was performed by immersing the samples in water for roughly one hour and assessing their weight pre-immersion and post-immersion. The porosity percentage can be obtained through the following in Equation 3.

$$\varphi\ (\%) = \frac{(m_{wet} - m_{dry})}{V\ (\text{cm}^3)} \times \frac{1}{\rho_{water}} \times 100\% \quad (3)$$

Where: m_{wet} is the mass of the saturated (wet) specimen (g); m_{dry} is mass of the dry specimen (g); V is the volume of the specimen (cm^3); ρ_{water} is the density of water (technically 1g/cm^3 at room temperature.

Table 2. Concrete mix proportions using natural fibres (BF, CCF, PLF), tabas sand, and superplasticiser (SNI 06-6867-2002)

Number of samples	CODE	Cement	Fine aggregate	Tabas sand	Superplasticizer	Water	Natural fiber (BF/CCF/PLF)
1	CTR-00-00	295.3	487.5	-	2.953	93.8	-
2	CTR-MS-00	236.3	341.3	86.3	2.363	131.3	-
3	MS-10BF	177.2	341.3	86.3	1.772	116.4	15
4	MS-11BF	177.2	331.5	86.3	1.772	116.8	16.5
5	MS-12BF	177.2	321.8	86.3	1.772	117.2	18
6	MS-10CCF	177.2	341.3	86.3	1.772	150	9.4
7	MS-11CCF	177.2	331.5	86.3	1.772	153.8	10.3
8	MS-12CCF	177.2	321.8	86.3	1.772	157.5	11.3
9	MS-10PLF	177.2	341.3	86.3	1.772	114	40.1
10	MS-11PLF	177.2	331.5	86.3	1.772	114.2	44.1
11	MS-12PLF	177.2	321.8	86.3	1.772	114.3	48.2

Figure 3. Mortar cube specimens (50 × 50 × 50 mm) of non-control mixtures incorporating natural fibers, labeled and prepared for compressive strength testing.

2.5.2 Environmental criteria

Total carbon dioxide (CO_2) emissions from mortar mixtures were calculated using a cradle-to-gate approach based on the Life Cycle Assessment (LCA) method (Wahedy et al., 2023). This calculation refers to the amount of materials used in 1 m³ of mortar and the emission factors of each material (Brazão Farinha et al., 2024). Emission factors are expressed in units of kg CO_2-eq/kg of material, which are obtained from literature and LCA databases such as Ecoinvent or previous studies (Swathi & Vidjeapriya, 2024). The calculation can be seen in equation 4.

$$\text{kg } CO_{2-eq} = \sum_{i=1}^{n} (Q_i \times EF_i) \quad (4)$$

Where Qi is the quantity of material i used (kg); EFi is the emission factor (CO_2 emission factor) of material i (kg CO_2-eq/kg material); n is the total amount of material components in 1 m³ of mortar (e.g., cement, sand, fiber, water, etc.).

2.5.3 Economic criteria

Economic criteria are calculated based on Equation 5, using current material unit prices in Indonesia in Indonesian Rupiah (IDR). For international comparison purposes, all prices are then converted to US Dollars (USD) using the current exchange rate (Leclerc & Zia, 2025). Price data is obtained from reliable local sources such as building material distributors, government e-catalogs, or average market prices for the current year (Tamburaka & Edwin, 2024). These values reflect the estimated actual costs of each mortar formulation in the context of the local and global economy.

$$\text{Total cost} = \sum (Q_m \times C_m) \quad (5)$$

Where Q_m is quantity of material m (in kg or kg/m3); C_m is cost per unit of material m (Rp/kg, IDR/kg, or USD/kg).

2.6. Data Collection Methods

TOPSIS is one of the multi-criteria decision-making methods, first introduced by Yoon and Hwang in 1981 (Tzeng & Huang, 2011). The core concept of TOPSIS is that the best alternative is the one that has the farthest distance from the perfect negative solution. This distance is measured geometrically using the Euclidean distance (the straight-line distance between two points) to determine how close each alternative is to the optimal solution.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method was used because it is capable of integrating several assessment criteria simultaneously in a single analysis system. In the context of this study, the TOPSIS method was chosen to determine the best mortar mix alternative based on five main parameters, namely compressive strength, density, porosity, CO_2 emissions, and material costs (Tzeng & Huang, 2011). The technical test results, emission calculations, and cost analysis data were entered into a decision matrix, then normalized and weighted according to the level of importance of each criterion. The final preference value was obtained based on the distance of each alternative from the positive and negative ideal solutions, so that the mixture with the highest preference value was considered the most optimal formulation (Yuva, 2023).

To solve decision-making problems using TOPSIS, several key steps must be understood, including:

1. Normalisation of the Decision Matrix
   In this step, TOPSIS requires converting the performance values of each alternative Ai for each criterion C_j into normalized scores.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i-1}^{m} x_{ij}^2}} \quad (6)$$

2. Weighted Normalized Decision Matrix
   In the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method, the normalized decision matrix is multiplied by the weight of each criterion to form the weighted normalized matrix:

$$y_{ij} = W \times r_{ij} \quad (7)$$

3. Positive and Negative Ideal Solution
   The positive ideal solution (A^+) and the negative ideal solution (A^-) are determined based on the ranking of the weighted normalized values (y_{ij}) as follows:

$$A^+ = (y_1^+, y_2^+, \ldots, y_n^+); \quad A^- = (y_1^-, y_2^-, \ldots, y_n^-); \quad (8)$$

4. Distance to the Ideal Solution
   The distance of the alternative Ai from the positive ideal solution is calculated as:

$$D_i^+ = \sqrt{\sum_{j-1}^{x} (y_i^+ - y_{ij})};\ i = 1,2 \ldots m \quad D_i^- = \sqrt{\sum_{j-1}^{x} (y_{ij} - y_i^-)};\ i = 1,2 \ldots m \quad (9)$$

5. Preference Value for Each Alternative
   The preference value for each alternative (V_i) is determined using the following formula:

$$V_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (10)$$

   A higher V_i value indicates that alternative A_i is more preferable.

3. RESULTS AND DISCUSSIONS

3.1 Technical testing

As shown in Figure 4, the increase in compressive strength in mixtures with bamboo fiber (BF) is due to the stiffer fiber structure and cellulose content of around 50–60%, which improves interparticle bonding in mortar. Conversely, coconut fiber (CCF) has high water absorption, which causes the formation of micro air voids during the drying process, thereby reducing density and compressive strength. This phenomenon was also reported by (Sathiparan et al., 2017), who stated that the addition of more than 1% coconut fiber reduces compressive strength due to increased internal porosity (Sathiparan et al., 2017).

3.2 Environmental criteria

To evaluate the environmental impact of the concrete mixtures, the CO_2 emission factors of each material component were identified. These emission factors, expressed in kilograms of CO_2 per kilogram of material, are based on literature and relevant environmental data sources. Table 3 presents the emission factors used for calculating the total embodied carbon in the mortar mixes.

Table 3. CO_2 emission factors of materials used in the concrete mix (kg CO_2/kg)

Materials	CO_2 emissions factor	References
Cement	0.036	(Miller, 2018)
Fine Aggregate	0.0021	(Miller, 2018)
BF	0.02	(Paiva et al., 2021)
CCF	0.002	(Paiva et al., 2021)
PLF	0.005	(Paiva et al., 2021)
Tabas sand	0.005	(Miller, 2018)
Superplasticizer	0.767	(Miller, 2018)
Water	0.000658	(Paiva et al., 2021)

Based on the emission factors listed in Table 4 and the quantities of each material used in the concrete mixtures, the total CO_2 emissions were calculated for each sample. Table 6 summarises the material composition (in kg) and the corresponding total CO_2-equivalent emissions per cubic meter of mortar, allowing for a comparative assessment of each formulation's carbon footprint.

3.3 Economic criteria

The economic analysis began by identifying the unit prices of each material used in the concrete mix. These prices were collected from local market data and relevant estimations, expressed in both Indonesian Rupiah (IDR) and United States Dollars (USD). Table 4 presents the cost per kilogram (or per liter where applicable) for each material, along with references indicating the source or basis of the pricing information.

Table 4. Unit prices of concrete mix materials based on local market rates (IDR and USD)

Materials	IDR (kg)	USD (kg)	References
Cement	2,498	0.1581	-
Sand	213.33	0.0135	-
Water	7.450 (per liter)	0.0047	Estimated PDAM (grup II) 2024
Superplasticizer	31000	1.9620	Estimated chemical material
BF	9.3	0.0006	From a local manufacturer
CCF	4.65	0.0003	Estimated dry cocomut fiber price
PLF	6.2	0.0004	Ready-to-use processed fiber
Basalt scoria	775	0.0491	Estimated local basalt stone price

Using the unit prices listed in Table 4 and the material quantities used in each mix, the total cost per mortar sample was calculated. Table 6 provides a breakdown of the material composition by weight for each sample, as well as the corresponding total cost in USD. This data supports the economic evaluation of each mixture, highlighting potential cost-efficiency differences across formulations.

Based on the cost analysis results, the price difference between the various mixes is only around ±0.01–0.02 USD/kg of mortar. However, in large-scale projects requiring 10,000 m³ of mortar, this small difference can have a significant impact on the total construction cost, especially in areas with limited access to cement. The use of local materials such as coconut fiber and bamboo not only reduces emissions but also reduces dependence on imported materials and long-distance transportation, which are high-cost components of infrastructure projects in tropical regions.

3.4 TOPSIS Method

The first step in the TOPSIS method involves constructing a decision matrix that includes all alternatives and their corresponding values for each evaluation criterion. In this study, the alternatives refer to mortar mixtures incorporating different types and dosages of natural fibers (bamboo fiber, coconut coir fiber, and pineapple leaf fiber). Five evaluation criteria were selected based on technical, environmental, and economic aspects:

1. Compressive strength (MPa)
2. Density (g/cm3)
3. Porosity (%)
4. Emissions (kg CO_2-eq)
5. Material cost (USD)

Table 5. Performance criteria of mortar alternatives and assigned weights for TOPSIS analysis

Alternative	Compressive strength	Density	Porosity	Total emissions (kg CO_2 -eq/m^3 mortar)	Total cost
CTR-00-00	2.8	2.1848	0.32	0.01398	5.319
CTR-MS-00	3.4	2.2464	0.64	0.01155	6.298
MS-10BF	3.2	1.8816	0.56	0.00926	5.651
MS-11BF	3.72	1.9576	0.32	0.00928	6.007
MS-12BF	3.8	2.0368	1.52	0.00917	7.366
MS-10CCF	2.96	2.008	1.44	0.00917	6.417
MS-11CCF	3.2	2.052	1.04	0.00917	6.301
MS-12CCF	3	2.1504	1.68	0.00917	6.840
MS-10PLF	3.2	2.1112	0.32	0.00973	5.641
MS-11PLF	3.28	2.136	1.52	0.00982	6.946
MS-12PLF	3	2.1544	0.64	0.00988	5.804
	BENEFIT	BENEFI'	BENEFIT	COST	COST
	3	1.5	1	2.5	2

Among these, compressive strength and density are considered benefit criteria where higher values are preferred, while porosity, CO_2 emissions, and cost are cost criteria, for which lower values are more desirable.

Table 6. Material composition and total CO_2 emissions of mortar samples (kg CO_2-eq/m³)

Number of Samples	Code	Cement (kg)	Fine Aggregate (kg)	Tabas sand (kg)	Superplasticizer (kg)	Water (kg)	Natural fiber (kg) (BF/CCF/PLF)	Total emissions (kg CO_2-eq/m^3 mortar)
1	CTR-00-00	0.01063	0.001023	0	0.00226	0.0000617	0	0.013981
2	CTR-MS-00	0.00851	0.000717	0.00043	0.00181	0.0000864	0	0.011554
3	MS-10BF	0.00638	0.000717	0.00043	0.00136	0.0000766	0.0003	0.009263
4	MS-11BF	0.00638	0.000696	0.00043	0.00136	0.0000769	0.00033	0.009273
5	MS-12BF	0.00638	0.000676	0.00043	0.00136	0.0000771	0.00036	0.009283
6	MS-10CCF	0.00638	0.000717	0.00043	0.00136	0.0000987	0.000188	0.009173
7	MS-11CCF	0.00638	0.000696	0.00043	0.00136	0.0001012	0.000206	0.009173
8	MS-12CCF	0.00638	0.000676	0.00043	0.00136	0.0001036	0.000226	0.009175
9	MS-10PLF	0.00638	0.000717	0.00043	0.00136	0.0000750	0.000802	0.009764
10	MS-11PLF	0.00638	0.000696	0.00043	0.00136	0.0000751	0.000882	0.009823
11	MS-12PLF	0.00638	0.000676	0.00043	0.00136	0.0000752	0.000964	0.009885

Table 7. Technical test results of concrete samples

Number of Samples	Code	Weight (g)	Wet Dry (g)	Compressive Strength (MPa)	Density	Porosity
1	CTR-00-00	273.1	273.5	2.8	2.1848	0.32
2	CTR-MS-00	280.8	281.6	3.4	2.2464	0.64
3	MS-10BF	235.2	235.9	3.2	1.8816	0.56
4	MS-11BF	244.7	245.1	3.72	1.9576	0.32
5	MS-12BF	254.6	256.5	3.8	2.0368	1.52
6	MS-10CCF	251	252.8	2.96	2.008	1.44
7	MS-11CCF	256.5	257.8	3.2	2.052	1.04
8	MS-12CCF	268.8	270.9	3	2.1504	1.68
9	MS-10PLF	263.9	264.3	3.2	2.1112	0.32
10	MS-11PLF	267	268.9	3.28	2.136	1.52
11	MS-12PLF	269.3	270.1	3	2.1544	0.64

The data for each criterion were obtained through laboratory testing and environmental calculation (LCA-based), while cost data were derived from local market prices and government e-catalogs. The decision matrix thus provides a quantitative basis for evaluating and ranking the mortar alternatives using the TOPSIS method.

In the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method, the terms benefit and cost are used to classify the types of criteria in the multi- criteria decision-making process. Benefit criteria are criteria that are more desirable or beneficial as their value increases (Behzadian et al., 2012). Examples include compressive strength, density, or efficiency, where higher values indicate better performance. Conversely, cost criteria are criteria where lower values are better, as they typically relate to expenses, environmental impact, or risk. Examples include cost, CO_2 emissions, porosity, or water consumption. In TOPSIS calculations, this classification determines whether a value will be approached toward the positive ideal solution (for benefits) or the negative ideal solution (for costs). Therefore, accurate identification between benefit and cost criteria is crucial for generating accurate and rational alternative rankings.

Table 8. TOPSIS preference values and final ranking of mortar mix alternatives

Alternative	Preference value	Calculation result	Rank
CTR-00-00	V1	0.354	11
CTR-MS-00	V2	0.410	6
MS-10BF	V3	0.383	9
MS-11BF	V4	0.392	8
MS-12BF	V5	0.451	1
MS-10CCF	V6	0.440	4
MS-11CCF	V7	0.423	5
MS-12CCF	V8	0.451	2
MS-10PLF	V9	0.374	10
MS-11PLF	V10	0.448	3
MS-12PLF	V11	0.393	7

The TOPSIS method ranking results show that the MS-12CCF mixture obtained the highest preference value of 0.451. This indicates a balance between mechanical strength, cost, and carbon emissions. Although bamboo fiber produces the highest compressive strength, its emissions and production costs are slightly higher than coconut fiber. The selection of MS-12CCF as the optimal formulation confirms that a multi-criteria approach can provide more rational decision results than a single assessment based on compressive strength alone. The results of this study are in line with, who reported that the use of bamboo fiber increased compressive strength by up to 15%. However, this study is more comprehensive because it not only reviews technical performance but also environmental and economic impacts through the TOPSIS approach. A similar approach was used by, but their focus was only on optimizing compressive strength and workability without considering the carbon footprint of the material.

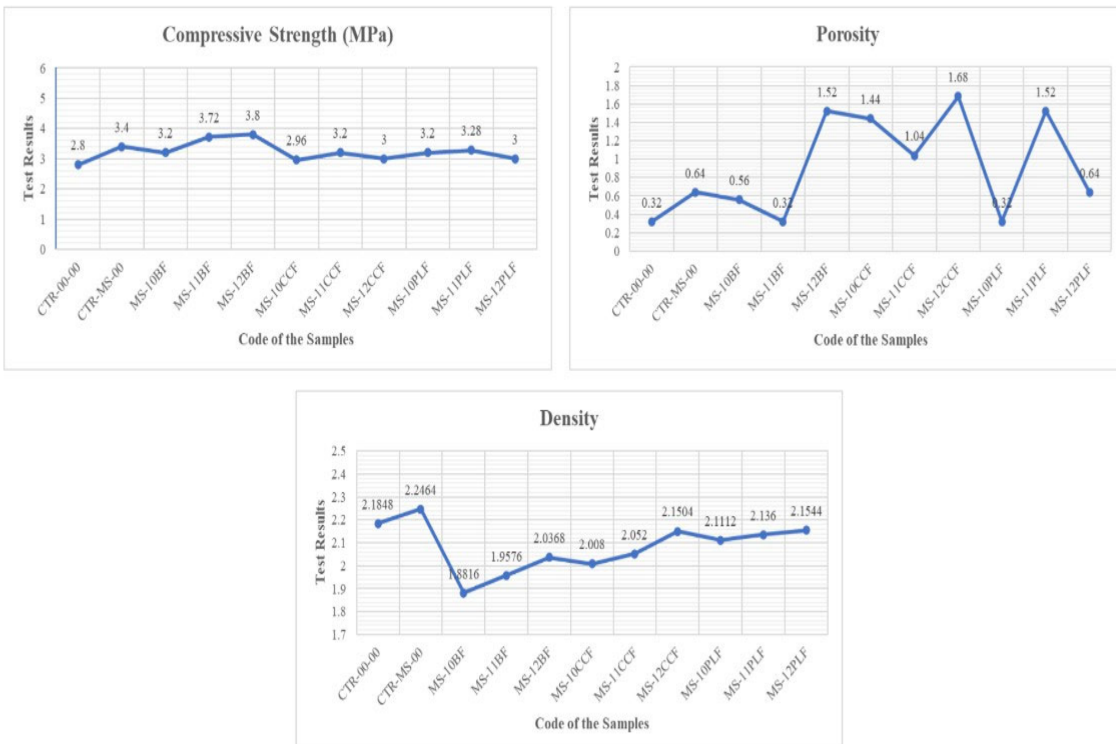

Figure 4. Variation of compressive strength of basalt-based mortar with different bio-fibers (BF, CCF, PLF)

Table 9. Performance criteria classification (benefit/cost) for mortar alternatives

Number of Samples	CODE	Cement (kg)	Fine Aggregate (kg)	Tabas sand (kg)	Superplasticizer (kg)	Water (kg)	Natural fiber (BF/CCF/PLF) (kg)	Total Cost
1	CTR-00-00	0.0467	0.0066	0	0.0000044	0.000442	0	0.054
2	CTR-MS-00	0.0374	0.0046	0.0042	0.0000036	0.000619	0	0.047
3	MS-10BF	0.0280	0.0046	0.0042	0.0000027	0.000548	0.00000883	0.037
4	MS-11BF	0.0280	0.0045	0.0042	0.0000027	0.000551	0.00000971	0.037
5	MS-12BF	0.0280	0.0043	0.0042	0.0000027	0.000553	0.00001059	0.037
6	MS-10CCF	0.0280	0.0046	0.0042	0.0000027	0.000707	0.00000553	0.038
7	MS-11CCF	0.0280	0.0045	0.0042	0.0000027	0.000725	0.00000606	0.037
8	MS-12CCF	0.0280	0.0043	0.0042	0.0000027	0.000743	0.00000665	0.037
9	MS-10PLF	0.0280	0.0046	0.0042	0.0000027	0.000538	0.00002360	0.037
10	MS-11PLF	0.0280	0.0045	0.0042	0.0000027	0.000538	0.00002596	0.037

Table 9 demonstrates that the total material cost of basalt-based mortar is only marginally affected by the incorporation of natural fibers, as evidenced by the narrow cost range observed across all mixtures. Based on the experimental results presented in this study, the reduction in cement content through the use of tabas sand and basalt scoria plays a more decisive role in cost control than the type or dosage of bio-fibers. Although mixtures containing coconut coir fiber (CCF) exhibit slightly higher water-related costs due to increased absorption, this effect does not translate into a significant increase in total cost. Similarly, pineapple leaf fiber (PLF), despite requiring pre-treatment, contributes negligibly to overall expenditure due to its low unit price. These findings align with the study's technical and environmental results, confirming that economic efficiency is primarily governed by binder optimization rather than fiber addition. Consequently, the integration of locally sourced bio-fibers can enhance mortar performance and sustainability without compromising economic feasibility, supporting the robustness of the multi-criteria evaluation adopted in this research.

4. CONCLUSIONS

This study evaluated the performance of basalt-based mortar incorporating three types of natural fibers: bamboo fiber (BF), coconut coir fiber (CCF), and pineapple leaf fiber (PLF) by assessing technical, environmental, and economic parameters. The TOPSIS method was employed to determine the optimal mortar formulation through multi-criteria decision analysis. Experimental testing showed that adding natural fibers influenced the compressive strength, density, and porosity of the mortar, while CO_2 emission calculations and cost analysis highlighted differences in environmental and economic performance. Among all alternatives, the MS- 12CCF mixture emerged as the most preferred, with the highest TOPSIS preference score, indicating a well-balanced combination of mechanical strength, low environmental impact, and cost-effectiveness. The study demonstrates that integrating local bio-fibers into mortar mixtures offers a viable solution for sustainable construction in Bali. Future research is encouraged to explore the long-term durability of these mortars under various environmental conditions and to scale up production for broader implementation in the building sector.

ACKNOWLEDGEMENTS

The author would like to express sincere appreciation to all individuals and institutions who have supported the completion of this research. Their contributions, whether in the form of technical assistance, access to resources, constructive input, or moral encouragement, have been greatly valued throughout this process.

The successful completion of this work would not have been possible without the collaboration and support received both directly and indirectly from various parties. The author is truly grateful for all forms of help that have enabled this research to reach its final form.

REFERENCES

Umoh, A. A., & Odesola, I. (2015). Characteristics of Bamboo Leaf Ash Blended Cement Paste and Mortar. *Civil Engineering Dimension*, *17*(1). https://doi.org/10.9744/ced.17.1.22-28

Alenezi, D., Mohammad, D., Alfoudari, F., Saeedi, M., Alajmi, R., & Mustafaraj, E. (2025). Strength and Water Absorption Behavior of Untreated Coconut Fiber-Reinforced Mortars: Experimental Evaluation and Mix Optimization. *Construction Materials*, *5*(3), 69. https://doi.org/10.3390/constrmater5030069

Almeida, M. P. B., Gomes, L. da S. S., Silva, A. R., Tamashiro, J. R., Paiva, F. F. G., Silva, L. H. P., & Kinoshita, A. (2025). Basalt Rock Powder in Cementitious Materials: A Systematic Review. *Resources*, *14*(6), 86. https://doi.org/10.3390/resources14060086

Anwar, F. H., El-Hassan, H., Hamouda, M., El-Mir, A., Mohammed, S., & Mo, K. H. (2022). Optimization of Pervious Geopolymer Concrete Using TOPSIS-Based Taguchi Method. *Sustainability*, *14*(14), 8767. https://doi.org/10.3390/su14148767

Astariani, N. K., Partama, I. G. N. E., & Dwi, I. G. A. R. C. S. (2023). Influence Substitution of Tabas Stone Waste which Coated Polyester Resin to Concrete Compressive Strength. *ASTONJADRO*, *12*(3), 738–745. https://doi.org/10.32832/astonjadro.v12i3.9065

Behzadian, M., Khanmohammadi, O. S., Yazdani, M., & Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*, *39*(17), 13051–13069. https://doi.org/10.1016/j.eswa.2012.05.056

Brazão Farinha, C. B., Maia Pederneiras, C., Infante Gomes, R., Bastos, D., & Veiga, R. (2024). Life Cycle Carbon Assessment of Mortars with Carbonated and Non-Carbonated Recycled Aggregates. *Applied Sciences*, *14*(17), 7442. https://doi.org/10.3390/app14177442

Indelicato, F., & Paggi, M. (2008). Specimen shape and the problem of contact in the assessment of concrete compressive strength. *Materials and Structures*, *41*(2), 431–441. https://doi.org/10.1617/s11527-007-9256-7

Kushwah, S., Singh, S., Agarwal, R., Nighot, N. S., Kumar, R., Athar, H., & Naik B, S. (2024). Mixture of biochar as a green additive in cement-based materials for carbon dioxide sequestration. *Journal of Materials Science: Materials in Engineering*, *19*(1), 27. https://doi.org/10.1186/s40712-024-00170-y

Leclerc, J., & Zia, A. W. (2025). Techno-economic analysis of cement-based composite mortars for energy-efficient buildings. *Green Technologies and Sustainability*, *3*(4), 100238. https://doi.org/10.1016/j.grets.2025.100238

Mathur, V. S., Farouq, M. M., & Labaran, Y. H. (2021). The carbon footprint of construction industry: A review of direct and indirect emission. *Journal of Sustainable Construction Materials and Technologies*, *6*(3), 101–115. https://doi.org/10.29187/jscmt.2021.66

Miller, S. A. (2018). Supplementary cementitious materials to mitigate greenhouse gas emissions from concrete: can there be too much of a good thing? *Journal of Cleaner Production*, *178*, 587–598. https://doi.org/10.1016/j.jclepro.2018.01.008

Mohammadi, A., & Ramezanianpour, A. M. (2023). Investigating the environmental and economic impacts of using supplementary cementitious materials (SCMs) using the life cycle approach. *Journal of Building Engineering*, *79*, 107934. https://doi.org/10.1016/j.jobe.2023.107934

Paiva, R. de L. M., Caldas, L. R., Martins, A. P. de S., de Sousa, P. B., de Oliveira, G. F., & Toledo Filho, R. D. (2021). Thermal-Energy Analysis and Life Cycle GHG Emissions Assessments of Innovative Earth-Based Bamboo Plastering Mortars. *Sustainability*, *13*(18), 10429. https://doi.org/10.3390/su131810429

Sathiparan, N., Rupasinghe, M. N., & H.M. Pavithra, B. (2017). Performance of coconut coir reinforced hydraulic cement mortar for surface plastering application. *Construction and Building Materials*, *142*, 23–30. https://doi.org/10.1016/j.conbuildmat.2017.03.058

Shooshtarian, S., Wong, P. SP., & Maqsood, T. (2025). Circular economy in modular construction: An Australian case study. *Journal of Building Engineering*, *103*, 112182. https://doi.org/10.1016/j.jobe.2025.112182

Swathi, B., & Vidjeapriya, R. (2024). A multi-criterial optimization of low-carbon binders for a sustainable high-strength concrete using TOPSIS. *Construction and Building Materials*, *425*, 135992. https://doi.org/10.1016/j.conbuildmat.2024.135992

Tamburaka, I., & Edwin, R. (2024). Economy, Energy, and Environment Impact on the Use of Ferronickel Slag Waste for Construction Project in Indonesia. *International Journal of Economy, Energy and Environment*, *9*(4), 90–97. https://doi.org/10.11648/j.ijeee.20240904.11

Tzeng, G.-H., & Huang, J.-J. (2011). *Multiple Attribute Decision Making*. Chapman and Hall/CRC. https://doi.org/10.1201/b11032

Wahedy, M. N., Sharbatdar, M. K., & Rezaifar, O. (2023). Mechanical, environmental, and economic assessment of sustainable cement mortar using Afghan natural pozzolan as a partial replacement for cement. *Construction and Building Materials*, *386*, 131574. https://doi.org/10.1016/j.conbuildmat.2023.131574

Yanti, G., Zainuri, Z., & Megasari, S. W. (2019). Peningkatan Kuat Tekan dan Kuat Lentur Beton Dengan Variasi Penambahan Serat Daun Nanas. *TEKNIK*, *40*(1), 71. https://doi.org/10.14710/teknik.v40i1.23390

Yuva, Y. (2023). Low-strength concrete properties in existing structures using NDT and core test results. *Journal of Building Engineering*, *76*, 107281. https://doi.org/10.1016/j.jobe.2023.107281