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Research article

Development of Cement-Based Composites Using Screw Pine Leaf Waste for Sustainable Community Products

Rarin Khuawaraphan[1], Supranee Wunsri[2], Palachai Khaonuan[3], Kosin Teeparuksapun[4], and Noppadon Podkumnerd[5*]

[1] College of Hospitality and Tourism, Rajamangala University of Technology Srivijaya Trang Campus, Trang, 92150, Thailand
[2] Faculty of Liberal Arts, Rajamangala University of Technology Srivijaya, Songkhla, 90000, Thailand
[3] Faculty of Liberal Arts, Rajamangala University of Technology Srivijaya, Songkhla, 90000, Thailand
[4] Faculty of Liberal Arts, Rajamangala University of Technology Srivijaya, Songkhla, 90000, Thailand
[5] Faculty of Liberal Arts, Rajamangala University of Technology Srivijaya, Songkhla, 90000, Thailand
* Correspondence: Noppadon.p@rmutsv.ac.th

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Abstract: This study demonstrates an innovative approach to waste material valorization through the development of reinforced fiber cement using screw pine (*Pandanus tectorius* Blume) leaf waste (SLW). First, the researchers study fiber cement composites with SLW, cement, and water in different ratios. The results showed that the 1:30:30 (w/w) ratio gave the highest compressive strength of 15.35 kg/cm^2; the density was 1,100±0.08 kg/m^3, and water absorption was 38.38 ± 1.61%. Then, the researchers studied the water absorption reduction of this fiber cement by coating it with a water-repellent for 15 minutes. The results indicated that the water absorption value was reduced to 33.78 ± 1.31%. Next, the researchers applied this fiber cement production method to produce cement pots, which were found to be well-formed and, when tested for compressive strength, had a value of 11.09 ± 0.23 kg/cm^2 and a water absorption value of 34.95 ± 2.23%. Later, the researchers conducted a study on customer satisfaction and cost-benefit analysis from the production of fiber cement pots; the result showed that the customer had an average satisfaction of 4.402 ± 0.101, which was very satisfactory. The production capacity is 1,000 pots, costing 12,600 baht, and the average cost per pot is 12.60 baht. If sold at 35 baht per pot, there will be a gross profit margin of 64.00%. Finally, this technology was transferred to the Khlong U-Tapao Watershed Community's weaving industry in Songkhla, Thailand, creating a sustainable revenue stream while supporting community-based tourism (CBT) initiatives.

Keywords: Cement pots; Screw pine leaf waste (SLW); Khlong U-Tapao Watershed Community

1. Introduction

The growing interest in turning agricultural waste into value-added products results from the emphasis on sustainable development and the circular economy. Plant-based lignocellulose fibers (LFs), which contain different amounts of cellulose, hemicellulose, and lignin, have shown great promise as composite reinforcement materials, especially for building applications. Due to their appealing qualities—such as increased durability, higher compressive strength, flexibility, lightweight, cost-effectiveness, and environmental sustainability—the incorporation of these natural fibers into cement-based composites has accelerated significantly since the 1990s [1-4]. Numerous agricultural waste streams have been the subject of in-depth research on using natural fiber reinforcement in concrete and cement-based products. The effective use of date palm fibers for reinforcing concrete [5], palm fibers in concrete bricks [6], and palm oil fibers in cement fiber board manufacturing [7] are noteworthy examples. These applications demonstrate the versatility and effectiveness of natural fibers in enhancing both the mechanical and physical properties of cement-based materials while providing environmental benefits through waste reduction. Screw pine (*Pandanus tectorius* Blume) (Figure 1), locally known as "Ka-Ra-Ket" in Thailand, "Mengkuang" in Malaysia, and "Woromo" in Indonesia, is a prevalent plant species in Southeast Asia [4,8,9]. This plant, characterized by its distinctive screw pine leaves, is particularly abundant in Thailand's Khlong U-Tapao Watershed Community, which serves as a primary material for traditional weaving. The community produces various items through local wisdom practices, including mats, storage containers, and bags. However, this production will generate a large amount of SLW, primarily from leaf preparation and cutting processes, creating a potential environmental burden if left unmanaged.

Figure 1. Screw pine (*Pandanus tectorius* Blume) (Photo by the author)

Khlong U-Tapao Watershed Community uses local wisdom to produce weaving products for daily use from screw pine leaves such as mats, storage containers, and bags (Figure 2A-C). However, in the production of screw pine leaf weaving products, it creates waste materials, as shown in Figure 3. These waste materials are generated during various production steps, including the process of preparing screw pine leaves and the cutting process. SLW is generated each year, and if there is no effective management, it will become the community's waste in the future.

Figure 2. Screw pine leaf basketry products, A) mat, B) handbag, and C) storage container (Photo by the author)

Figure 3. Screw pine leaf production: A) preparation of screw pine leaf, B) production of basketry product, and C) SLW (Photo by the author)

In the context of Thailand's commitment to the Bio-Circular-Green (BCG) economic model and sustainable development goals, finding innovative ways to utilize such agricultural waste is crucial. The Khlong U-Tapao Watershed Community's screw pine weaving industry presents an opportunity to demonstrate how traditional craft waste can be transformed into valuable products while addressing environmental concerns and supporting community development. This research aims to develop and optimize a method for producing cement pots reinforced with SLW, creating a practical solution for waste utilization while generating additional income opportunities for the community. The specific objectives include determining the optimal mixture ratios of SLW, cement, and water for pot production, evaluating the physical and mechanical properties of the reinforced cement composites, developing a water-resistant treatment process to enhance product durability, analyzing the economic viability of production and facilitating technology transfer to the community. The significance of this research extends beyond waste management, as it presents a model for integrating traditional craft waste into modern, sustainable products while supporting CBT initiatives. This approach aligns with Thailand's BCG economic model, promoting sustainable development that balances social, economic, and environmental considerations. Through this research, we demonstrate how local agricultural waste can be transformed into valuable products, creating a circular economy model that benefits both the environment and the community. The findings contribute to the growing knowledge of natural fiber reinforcement in cement-based materials while providing a practical framework for community-level implementation of sustainable waste management solutions.

2. Materials and Methods

2.1 Preparation of SLW

SLW was obtained from the screw pine weaving group, Mae Thom Sub-district, Bang Klam District, Songkhla Province. It was cut into small pieces with a size of 1 inch long. The SLW was dried using sunlight. After that, the SLW was blended using a high-speed blender (Otto BE-127A; Thailand) at 6,000 rpm for 30 seconds to separate fibers from the leaves. The SLW was stored in a plastic bag to protect them from moisture at room temperature.

2.2 Optimization of mixtures ratio of fiber cement composites

In general, the production of fiber cement composites uses three types of raw materials: cement, water, and lignocellulosic fiber [3]. Therefore, this experiment investigated 4 mixture ratios of cement, water, and SLW, as shown in Table 1. A control experiment was performed where SLW was not. After that, pour the mixture into a 20L plastic container and mix it well using a mud mixer (Stanley-SDR1400; China) at 480 rpm for 5 minutes. The studied mixture was investigated by forming the sample into a square shape with a dimension of 50 x 50 x 20 mm (width x length x thickness). It was then dried at 100-110°C using a hot air oven (Binder ED260; Germany) and allowed to cool before being tested for density and water absorption tests according to the ASTM C 642-21 method [10]. The specimens were baked at 100-110°C in a hot air oven for 24 hours and cooled. They were weighed using an electric balance (Sartorius Quintix3102-1S; Germany) and immersed in water for 24 hours. The specimens were then weighed again. After completing the above process, the sample's percentage of water absorption was analyzed The compressive strength test according to the

ASTM C39/C39M-21 method [11], was investigated using a compression testing machine (Marshall testing machine S215PA171; Italy. The date wer anzlyed for variance using one-way ANOVA, and differences between group means were compared using Duncan's Multiple Range Test (DMRT), at a significance level of 0.05. The strongest and weakest samples were used to study the structure using a Trinocular Fluorescence Stereo Microscope (TFSM) (Leica M205FCA, Germany).

Table 1. Optimization of raw materials ratios

Specimen	SLW (g)	Cement (g)	Water (g)
S1	1.0	10.0	10.0
S2	1.0	20.0	20.0
S3	1.0	30.0	30.0
S4	1.0	40.0	40.0
Control	-	10.0	10.0

2.3 The water-repellent coating of fiber cement composites reinforced with SLW

The water-repellent coating of the cement composites reinforced with SLW was investigated using the optimized mixture ratio of fiber cement composites from the previous experiment. In this experiment, the NK GUARD S-80 (NICCA Chemical) was used to increase the water-repellent properties of the fiber cement composites reinforced with SLW. The water-repellent coating method was modified from Podkumnerd *et al.* [12], Briefly, the NK GUARD S-80 was mixed with water at a ratio of 2:8 (w/w) in a 250 mL beaker. After that, the specimens were soaked in the mixture three different times (5, 15, and 30 minutes) and further studied for water resistance, the water absorption test according to the ASTM C 642-21 method [10].

2.4 Production of cement pots reinforced with SLW

Cement pots reinforced with SLW were produced using the best-performing ingredients from experiment 2.2 and poured into plastic molds, covered with a hemp sack to prevent water evaporation, and left for 24 hours. After that, it was removed from the mold and left to dry for 7 days. They were then dried in a hot oven at 100-110°C for 24 hours and left to cool. The waterproof coating was performed by immersing the pots in a 10L container filled with water-repellent for the appropriate time from Experiment 2.3 and then baking at 100-110°C for 24 hours. The fabricated pots were tested for water absorption according to the ASTM C 642-21 method [10] and for compressive strength according to the ASTM C39/C39M-21 method [11].

2.5 Customer Satisfaction Analysis

After transferring technology for producing cement pots reinforced with SLW to the community, the researchers study customer satisfaction, according to Kotler and Keller [13]. Customer satisfaction analysis emphasizes the Expectation-Disconfirmation Model and various methods businesses use to measure and manage customer perceptions. One of the most commonly used satisfaction measurement scales consists of five levels: 5= Very Satisfied, 4= Satisfied, 3= Neutral, 2= Dissatisfied, and 1= Very Dissatisfied. The questionnaire data on the satisfaction of the sample group was collected between May - June 2023 using a sample group of people living in Bang Klam District, Songkhla Province, selected using Yamane's formula [14]. After that, the data were analyzed for the mean and standard deviation. The evaluation criteria were a rating scale according to Likert [15], which has 5 levels: 4.51-5.00 most satisfied, 3.51-4.50 very satisfied, 2.51-3.50 moderately satisfied, 1.51-2.50 slightly satisfied, and 1.00-1.50 least satisfied.

2.6 Cost-benefit analysis

The researchers analyzed the cost and return on the product to enable the community to effectively sell the produced products and generate additional income for the community.

Total costs analysis according to Horngren *et al*. [16].

Total Cost = Direct Material + Direct Labor + Manufacturing overhead

Break-even point, according to Garrison *et al*. [17].

Break-event point = Fixed cost / Contribution margin ratio

According to Cooper and Kaplan [18], the gross profit margin ratio.

Gross Profit margin ratio = (Gross profit x 100) / Sale revenue

2.7 Technology transfer to the community

The technology for producing cement pots reinforced with SLW was transferred to the Screw Pine Leaf Basketry Products Group in the Khlong U-Tapao Watershed Community, located in Mae Thom Sub-district, Bang Klam District, Songkhla Province. This initiative aims to enhance the value of waste materials and support CBT activities within the community.

3. Results and Discussion

3.1 Characteristics of SLW

The transformation of SLW through processing revealed distinct physical changes. The initial waste material, characterized by its fibrous nature, underwent significant modification through the blending process. This processing step was crucial in achieving optimal fiber separation, directly impacting the material's bondability with cement. The processed fibers demonstrated improved potential for cement matrix adhesion, a critical factor for the composite's structural integrity. Figure 4A shows the SLW. After blending, SLWs were obtained, as shown in Figure 4B. These SLWs will further improve the adhesion to the cement.

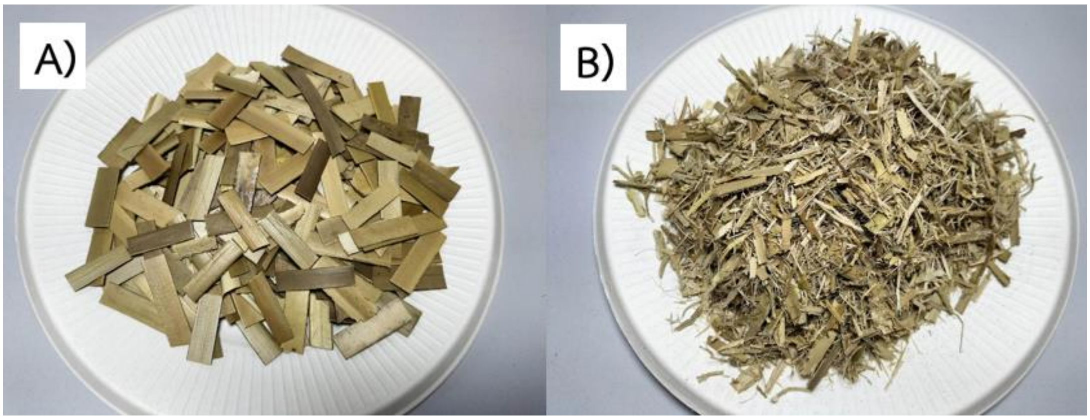

Figure 4. A) SLW and B) SLWs after the blending step

3.2 Mixtures ratios for fiber cement composites

From the forming of fiber cement composites with SLW using 4 different specimens, it was found that it could be formed (shown in Figure 5). When considering the characteristics of the formed samples, it was found that S1 gave a lot of SLW, but they were not very tightly bonded together. However, when the amount of cement was used, namely S2, S3, and S4, it was found that the fibers bonded together more tightly. This result is consistent with the report of Faridul Hasan *et al.* [1]. Mixing lignocellulose, cement, and water was an efficient, cheap, and easy way to fabricate the pots. However, the proportion of lignocellulose needs to be optimized.

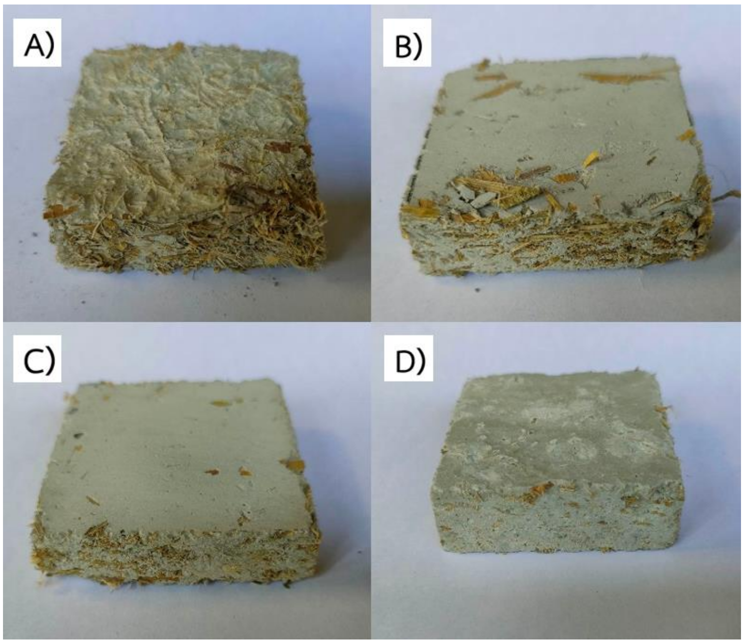

Figure 5. Characteristics of specimens of cement reinforced with SLW at different mixture ratios of SLW: A) S1, B) S2, C) S3, and D) S4

The results of the density test of the specimens are shown in Table 2. It showed that when the amount of cement was increased, it resulted in a higher sample density. In specimen 1, the density was 860 ± 0.09 kg/m^3, and this was different at a significance level of 0.05 from S2, S3, and S4 with densities of 1,040 ± 0.09, 1,100 ± 0.08, and 1,180 ± 0.08 kg/m^3, respectively. The density of the sample obtained from S2-S4 meets the Thai Industrial Standard, TIS standards. 878-2537 defines industrial product standards (cement-bonded particleboards: high density) that must have an average density in the range of 1,100–1,300 kg/m^3 [19].

The specimen's properties for water penetration were tested; the result is shown in Table 2. It was found that increasing the amount of cement in the mixture decreased water absorption. The water absorption in S1 was 53.19 ± 3.09%, which was different from S2, S3, and S4 (40.36 ± 2.21, 38.38±1.61%, and 36.35 ± 1.97%, respectively) at a significance level of 0.05. It can be seen that using a larger amount of SLW has a great effect on water adsorption because it creates more cavities in the sample, resulting in better water retention and water-holding capacity. This is consistent with another report that increased the ratio of sawdust from *Anogeissus leiocarpus* in cement, which increased water absorption and swelling of concrete by 135.76% and 16.67%, respectively [20].

Table 2. Density and water absorption test results

Specimen	Density* (kg/m^3)	Water absorption* (%)
S1	860 ± 0.09^a	53.19 ± 3.09^c
S2	1,040 ± 0.09^b	40.36 ± 2.21^b
S3	1,100 ± 0.08^{bc}	38.38 ± 1.61^{ab}
S4	1,180 ± 0.08^{bc}	36.35 ± 1.97^a
Control	1,210 ± 0.08^c	35.11 ± 0.63^a

* Different characters in each column illustrated the average comparison by DMRT at a significantly different level of 0.05.

From the compressive strength test with a compression testing machine, it was found that using an optimum amount of SLW had a significant effect on the strength of the sample. The use of SLW with cement in S3 gave the highest compressive strength of 15.35 kg/cm^2, which was different from the other specimen at a significance level of 0.05, followed by S2 with a compressive strength of 14.02 ± 0.48 kg/cm^2, and followed by S4

(10.24 ± 0.66 kg /cm²). S1 gave a compressive strength of only 3.37 ± 0.76 kg/cm² (Table 3). However, excessive use of SLW decreases mechanical strength due to a decrease in cementitious cohesion. This is consistent with the research of Usman *et al.* [21], who reported that the compressive strength of samples with sawdust (SD) decreased with increasing percentage of SD. The decreased compressive strength may be due to the larger SD particles, which increased the air content in the samples, resulting in increased overall porosity and weaker internal structure. This result is consistent with the images recorded with TFSM at 15X and 50X magnification, as shown in Figure 6 and Figure 7. Excess SLW can cause weakly bound (Figure 6A and Figure 7A), resulting in many cavities and thus less compressive strength.

Table 3. Compression resistance tested by compression testing machine

Specimen	Compressive strength* (Kg/cm²)
S1	3.37 ± 0.76[b]
S2	14.02 ± 0.48[d]
S3	15.35 ± 0.63[e]
S4	10.24 ± 0.66[c]
Control	1.62 ± 0.24[a]

*Different characters in each column illustrated average comparison by DMRT at significantly different at the 0.05 level

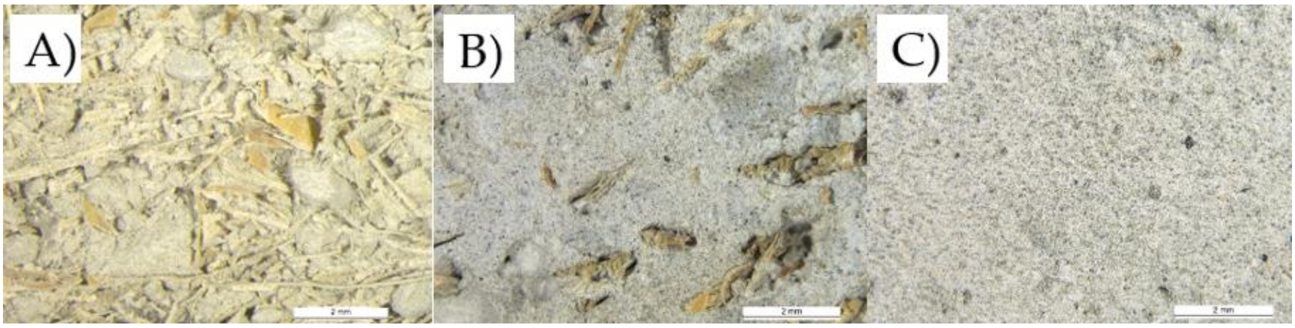

Figure 6. Photos recorded with TFSM of cement reinforced with SLW at 15X magnification A) S1 (1:10:10), B) S2 (1:30:30), and C) control

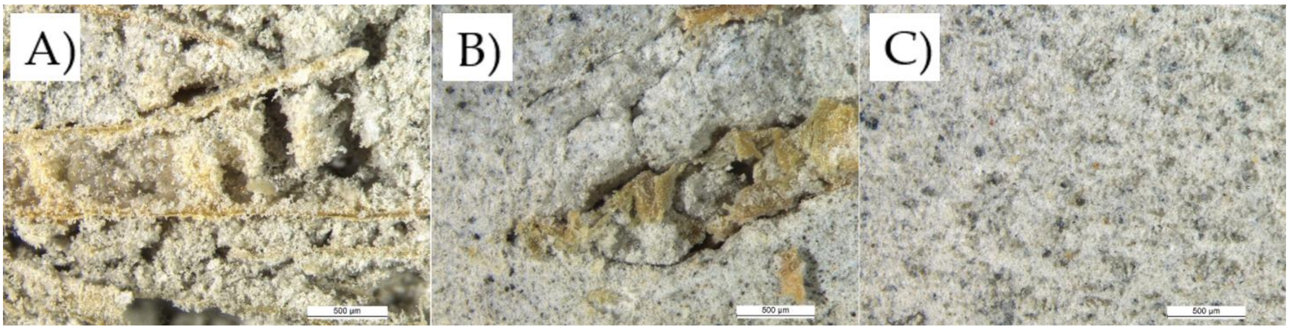

Figure 7. Photos recorded with TFSM of cement reinforced with SLW at 50X magnification A) S1 (1:10:10), B) S2 (1:30:30), and C) control

3.3 The water-repellent coating of fiber cement composites reinforced with SLW

The study results of using fiber cement composites reinforced with SLW showed good water absorption (Table 2). Therefore, the researchers studied the method of reducing water absorption by applying the water-repellent coating to coat the samples with the best compressive strength, S2 and S3 (Table 4). It was found that soaking the samples in a water-repellent coating resulted in a more significant reduction in water absorption. S2, soaked in the water-repellent coating for 0, 5, 15, and 30 minutes, gave the percentage of water absorption of 45.17 ± 0.98%, 39.27 ± 0.69%, 34.18 ± 0.5%, and 32.52 ± 1.45%, respectively. It was found that soaking the samples for 15 and 30 minutes gave water absorption values that were not significantly different at the confidence level of 0.05. S3 gave the percentage of water absorption values of 44.01 ± 0.79%, 37.54 ± 1.48%, 33.78 ± 1.31%, and 31.81 ± 1.12%, respectively. It was also found that soaking the samples for 15 and 30 minutes gave water absorption values that were not significantly different at the confidence level 0.05.

Table 4. Water absorption of fiber cement composites reinforced with SLW after coating by using the water-repellent coating at different durations

Time (Minute)	Water absorption (%)	
	S2	S3
0	45.17 ± 0.98[c]	44.01 ± 0.79[c]
5	39.27 ± 0.69[b]	37.54 ± 1.48[b]
15	34.18 ± 0.57[a]	33.78 ± 1.31[a]
30	32.52 ± 1.45[a]	31.81 ± 1.12[a]

*Different characters in each column illustrated the average comparison by DMRT at a significantly different level of 0.05.

3.4 Production of cement pots reinforced with SLW

The results of the previous experiments showed that the production of fiber cement composites reinforced with SLW using S3, which uses SLW together with cement in a ratio of 1:30, gives the highest compressive strength, highest density, and lowest water absorption rate. Coating fiber cement composites reinforced with SLW in the water-repellent coating (NK GUARD S-80) for 15 minutes can reduce water absorption. Therefore, researchers have applied this method to produce cement pots reinforced with SLW. The method started by mixing raw material and pouring it into a mold modified from plastic pots (Figures 8A and 8B). This fabrication method was easy, cheap, and suitable for the community. After the mixture had solidified well, the pot was removed from the mold, polished with sandpaper, and dried with sunlight. The weight of the resulting pot was approximately 600 g with a capacity of 360 mL (Figure 8A). The compressive strength of the pot was 11.09 ± 0.23 kg/cm^2. After coating with water-repellent and testing by soaking the pot in water-repellent coating for 15 minutes, an average water absorption of only 34.95 ± 2.27% was obtained.

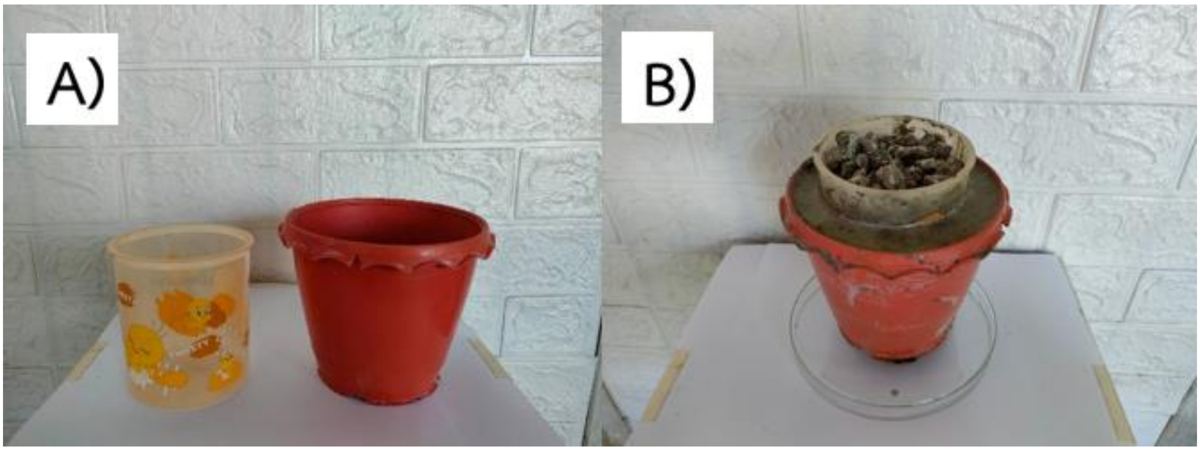

Figure 8. Fabrication of cement pot reinforced with SLW A) An experiment was set up with pot molds. B) Pot forming

The fabrication of cement pots reinforced with SLW can be an alternative way to manage waste in the community. This is consistent with Lertwattanaruk, P., and Suntijitto [22], who investigated the use of coconut coir and oil palm fibers, waste materials from the agricultural industry, to produce roof sheet and siding materials. It was found that both types of natural fibers, at a ratio of 5% by weight of cement in the mixed proportion, resulted in products with physical and mechanical properties according to the specified standards. A set of cement pots reinforced with SLW was fabricated with a pot and a pot pad (Figure 9A) and used for growing small plants such as cacti and Glochidion (Figure 9B) so that the community can use it as a community product.

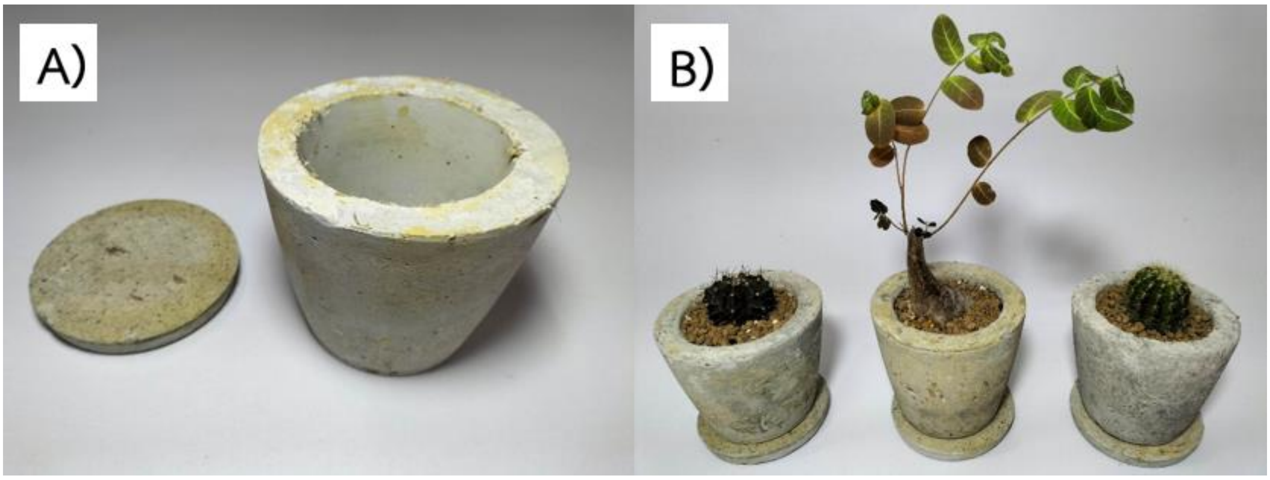

Figure 9. A) The cement pot reinforced with SLW B) planting of small plants in the pots

3.5 Customer satisfaction analysis

The product satisfaction analysis of the sample group, shown in Table 5, found that the average satisfaction in all aspects was 4.402 ± 0.101, which was at a high level. The aspect of usability had the highest average of 4.669±0.088, followed by the aspect of product quality, with an average of 4.463 ± 0.097; the aspect of design and beauty, with an average of 4.377 ± 0.092; and the aspect of value for money, with an average of 4.101 ± 0.117.

Table 5. Product satisfaction evaluation

Evaluation criteria	Satisfaction level ($\bar{x}$±S.D.)	Evaluation results
Product Quality	4.463 ± 0.097	very satisfied
Design and beauty	4.377 ± 0.092	very satisfied
Value for money	4.101 ± 0.117	very satisfied
Usability	4.669 ± 0.088	most satisfied
The average satisfaction	**4.402 ± 0.101**	**very satisfied**

3.6 Cost-benefit analysis

Total cost analysis (Table 6) shows that the production of 50 pots per production cycle costs 1,580 baht, and the average total cost per pot is 31.60 baht. The production of 500 pots per production cycle costs 6,800 baht, and the average total cost per pot is 13.60 baht. If producing up to 1,000 pots per production cycle, it costs 12,600 baht, and the average total cost per pot is only 12.60 baht. From the data, it can be seen that production costs will be significantly reduced when there is continuous production in large quantities.

Table 6. Total cost analysis

Specification	50 pots	500 pots	1,000 pots
Direct materials (DM)	125	1,250	2,500
Direct labor (DL)	250	2,500	5,000
Manufacturing overhead-variable cost (OHVC)	205	2,050	4,100
Manufacturing overhead-fixed cost (OHFC)	1,000	1,000	1,000
Total cost (baht)	**1,580**	**6,800**	**12,600**
Averrage cost/pice (baht)	**31.60**	**13.60**	**12.60**

Break-even analysis (Table 7) found that if the selling price of a pot is set at 35 baht per pot, at least 43 pots must be produced per cycle to reach the break-even point. However, when the pots are sold together with the plants for 100 baht per set, the break-even point is 15 sets per production cycle. Therefore, selling the pots with the plants is an interesting way to achieve a better break-even point.

Table 7. Break-even point analysis

Specification	Pot	Pot+Plant
Selling Price (Baht)	35	100
Direct Materials (DM)	2.5	2.5
Direct Labor (DL)	5	5
Manufacturing Overhead-Variable cost (OHVC)	4.1	24.1
Manufacturing Overhead-Fixed cost (OHFC)	1,000	1,000
Break-even point	42.74	14.61

Gross profit margin analysis (Table 8) shows that the production of 500 pots will have a gross profit margin of 61.14%, and the production of 1,000 pots will have a similar gross profit margin of 64%. The gross profit margin from producing 1,000 pots was found to be 66.40%, and when producing pots with plants, the gross profit margin was found to be 61.40%. The data shows that higher volume production will result in higher gross profit margins, resulting in lower total production costs.

Table 8. Gross Profit Margin analysis

Specification	500 Pots	1,000 Pots	500 (Pots+Plants)	1,000 (Pots+Plants)
Selling Price (Baht)	17,500	35,000	50,000	100,000
Cost of Sales (Baht)	6,800	12,600	16,800	32,600
Gross Profit Margin (%)	**61.14%**	**64.00%**	**66.40%**	**61.40%**

3.7 Technology transfer to the community

To generate an income from waste materials and to create a learning site for tourism in the screw pine weaving community, Khlong U-Tapao Watershed, Songkhla Province, the fabrication technology of cement pots reinforced with SLW was transferred to the screw pine leaf basketry products group, Mae Tom Sub-district, Bang Klam District, Songkhla Province (Figure 9). The community has applied the production process of cement pots reinforced with SLW as a part of CBT activity, which has received good interest from tourists.

Figure 9. A) technology transfer to the community, B) production of pots to promote CBT

4. Conclusions

The work presented the strategy for product development of cement-based composites using SLW from weaving production in Khlong U-Tapao Watershed Community, Mae Thom Sub-district, Bang Klam District, Songkhla Province. SLW from the community's basketry production process could be used as reinforced material for cement pots. The ratios of raw materials, including SLW, cement, and water, play a key role in compressive strength. The optimum ratio of the material was 1:30:30 (w/w), and the highest compressive strength was 15.35±0.63 kg/cm^2. The density was 1,100±0.08 kg/m^3, meeting the Thai Industrial standard, TIS 878-2537 requirement. The water absorption property of the pot can be controlled by using a water-repellent substance, which could reduce water adsorption from 38.38 to 33.78%. When this process was used to produce cement pots mixed with fiber, it was found that the cement pots refocused with SLW produced had the same properties as fiber cement composite with SLW. From the study of customer satisfaction, it was found that customers were delighted. The production capacity is 1,000 pots, costing 12,600 baht, and the average cost per pot is 12.60 baht. If sold at 35 baht per pot, there will be a gross profit margin of 64.00%. Therefore, cement pots reinforced with waste material, such as SLW, can be an alternative way to manage waste. The prototype pots from this research use 20 grams of fiber per pot, and larger amounts of SLW can be used when producing larger pots. When the technology is transferred to the community, it can generate income directly by selling pot and indirectly as it can be part of the activity in CBT.

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