Development and Production of Artificial Log Composite for Prefabricated Modular Home

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Abstract

The purpose of this study is to develop artificial log composites with light-weight and low thermal conductivity properties, and to demonstrate the production of prefabricated modular home. The artificial log composites were designed and produced with five different types of pipe including: polyvinyl chloride pipe (PVC Pipe), PVC pipe reinforced with recycled paper pulp cement core, recycled paper pulp cement reinforced with water plastic bottle core, recycled paper pulp cement reinforced with PVC pipe core, and recycled paper pulp cement reinforced with round bar steel. The physical, mechanical, and thermal conductivity properties of the artificial log composites were investigated and compared to common building materials in the market. Then the proper artificial log composites were selected to produce the prefabricated wall panels for demonstrating the production of prefabricated modular home. From the results, it found that the artificial log composites from recycled paper pulp cement reinforced with PVC pipe core was the proper composite material which possessed good properties and low cost. It was produced and installed on prefabricated modular homes easily and rapidly and could follow the expected work plans. The total cost of the prefabricated modular home was 11,415 Baht/square meter. Finally, this artificial log composite is a new alternative material for producing modular homes in the commercial business.

Keywords: Fiber cement material, Log, Wall panel, Log home, Prefabricated home

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1. Introduction

In the past, countries in Europe, America, and Scandinavia used logs to build structures and walls because of the abundant supply of soft wood, which was easy and convenient to cut with tools. These logs were used as the main material for building houses that were beautiful, secure, strong, and could protect its inhabitants from many dangers. Therefore, log house (Figure 1 a) was popular in the past and wood became the main material used in building places to live. The Swedish log house was one of the shapes that was famous for its use in wall structures since it could prevent outside water and weather from entering, due to its design of least amount of wall joint area and decoration time.

In Thailand, the area of forests has declined. The government sector is taking control of logging and transportation, which has resulted in a high price for wooden construction materials. Therefore, synthetic materials are used as a replacement and have become popular. These synthetic materials are used as decorative materials and ready-made movable walls. However, these synthetic materials still have limitations in terms of fragility and less ability in heat prevention. Wood is a main component of old building materials of traditional residential houses than in the present. According to past studies, Khedari, Suttisonk, Pratinthong & Hirunlabh (2001); Khedari, Charoenvai & Hirunlabh (2003) and Khedari, Watsanasathaporn & Hirunlabh (2005) developed agricultural fiber based composite. Fibers in composite can be used as building materials with low density and low thermal conductivity. Lertsutthiwong, Khunthon, Siralertmukul, Noomun & Chandrkrachang (2008); Souza (2000) and Folorunso & Anyata (2007) studied paper based composite and found that it had some good physical and mechanical properties. The studies on paper pulp cement (Sangrutsamee, 2012a; 2012b) found that recycle paper as available in abundance throughout the world, which could be used easily and quickly for using paper pulp as a raw material. The objective of this study is to develop and test new artificial log composites for their physical, mechanical and thermal properties, and to evaluate this new prefabricated wall material and produce a prototype for a prefabricated modular home.

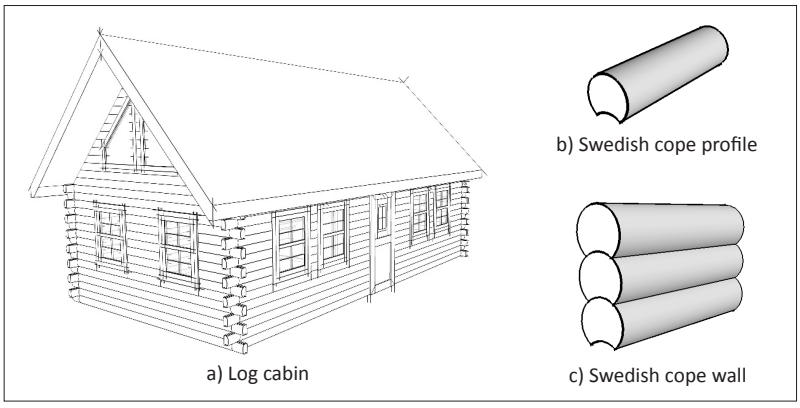


Figure 1. Log cabin and Swedish cope wall.

2. Materials and Method

2.1 Materials

There were five types of artificial log materials with radius 3" in Figure 2 were designed and developed for testing:

1. 3" PVC pipe class 5.5
2. 3" PVC pipe reinforced with recycled paper pulp cement core
3. Recycled paper cement pulp reinforced with water bottles core (2 mm. thickness of a layer coated surface)
4. Recycled paper pulp cement reinforced with 1 ½" PVC core (2 mm. thickness of a layer coated surface)
5. Recycled paper pulp cement reinforced with 6 mm. round bar steel (2 mm. thickness of a layer coated surface)

2.2 Production Process

Type 1 specimens use PVC pipe in the local building material market. Type 2 to type 5 specimens were produced as follows:

1. Prepare mold and core materials and mold.
2. Prepare and weigh pulp paper soaked in water for 1 day then spun as paper pulp.

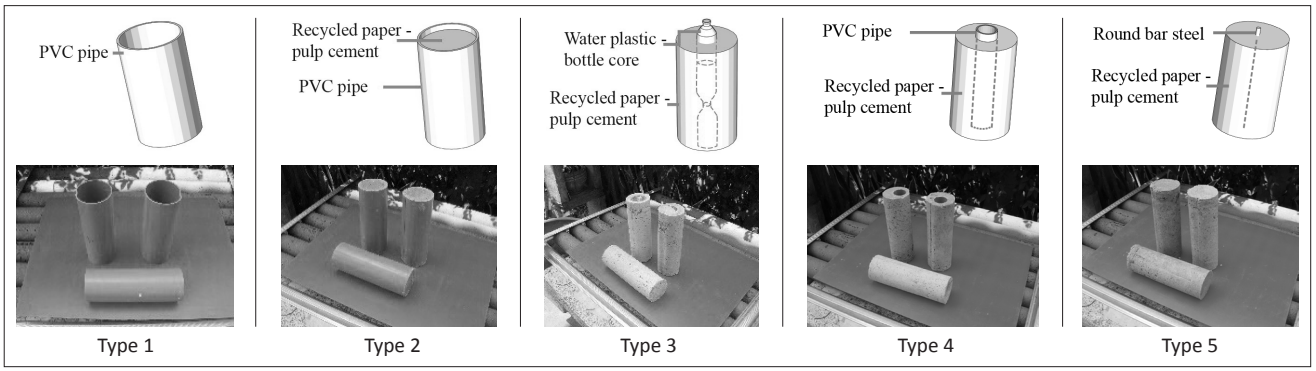


Figure 2. 5 types of the produced artificial log materials.

3. Weigh and prepare raw materials with a ratio of 1:4:0.2 (cement : water : paper pulp by weight).

4. Mix and spin all materials using a mechanical stirrer for 5 minutes.

5. Pour the materials in the mold then leave the mold after 24 hours.

6. Cure the specimens at room temperature for 21 days then prepare specimen surface.

7. Test the specimens at 28 days.

2.3 Testing Procedure

Three pieces of specimens were prepared and tested as the following procedures:

• Testing and calculating density equation

$$p = \frac{m}{v} \qquad \text{(Eq. 1)}$$

Where :

p = average density (kg/cm^3)
M = mass (g)
V = volume (cm^3)

• Testing and calculating water absorption equation

$$WA = \frac{M2-M1}{M1} \times 100 \qquad \text{(Eq. 2)}$$

Where:

WA = Water absorbed (%)
M2 = Final weight of material (g)
M1 = Initial of weight of material (g)

• Testing and calculating compressive strength equation

$$C = \frac{P}{A} \qquad \text{(Eq. 3)}$$

Where:

C = Compressive strength (kg/cm^2)
P = Load applied (kg)
A = Specimen area (cm^2)

• Thermal conductivity was performed according to ASTM C 177 and calculated to find heat resistance (R-value)

$$R = \frac{\Delta x}{k} \qquad \text{(Eq. 4)}$$

Where:

R = Heat resistance (m^2 °K/W)
Δx = Thickness of specimen (m.)
k = Thematerial'scoefficientofthermal conductivity (W/m °K)

• Evaluating production and assembly of artificial log and prefabricated modular home was observed, recorded and analyzed in the field test.

2.4 Development of artificial log and prefabricated modular home

2.4.1 Artificial log materials

This artificial log was developed from Swedish cope profile as shown in Figure 1b. and Figure 1c. as a new prefabricated wall panel with low thermal conductivity and light weight.

When good property and optimum type of artificial log was selected to produce the prototype artificial log for assembling as prefabricated modular home, the artificial log was manufactured and assembled as a prefabricated wall panel as shown in Figure 3.

2.4.2 Design and development of prefabricated modular home system

The modular home is a method of industrial home design that takes into account proportion, material, structure, manufacturing and assembly process using a standard unit system in order to save material, time, and cost.

This artificial log will be produced as a prefabricate wall component before they will be installed and inserted on wall structural stud of the prefabricated modular home as shown in Figure 4.

The prefabricated modular home prototype was designed and built moluding 3 main components 1) base component 2) body component and 3) roof component as shown in Figure 5. The modular's dimension is 0.90 m. leugth, complying with door, window, ceiling and material sizes.

The main structure and material of the prefabricated modular home are as below:

1) Foot structure: reinforced concrete dimension 45x45x40 cm.

2) Column and beam structure: square steel tube 4"x4" thickness 3.2 mm. and 2"x4" Rectangular steel tube thickness 3.2 mm.

3) Floor material: Fiber cement panels 30x300 cm. thickness 2.5 cm.

4) Wall Structure and material: 2"x4" U channel steel at thickness 1.2 mm and artificial log from recycled paper pulp cement reinforced with 1 ½" PVC pipe core.

5) Ceiling structure and material: ceiling T grid system and gypsum board thickness 6 mm.

6) Doors and windows: wooden doors and window with aluminum frame clear glass materials.

7) Roof structure and materials: rectangular steel tube structure and fiber cement tile roofing.

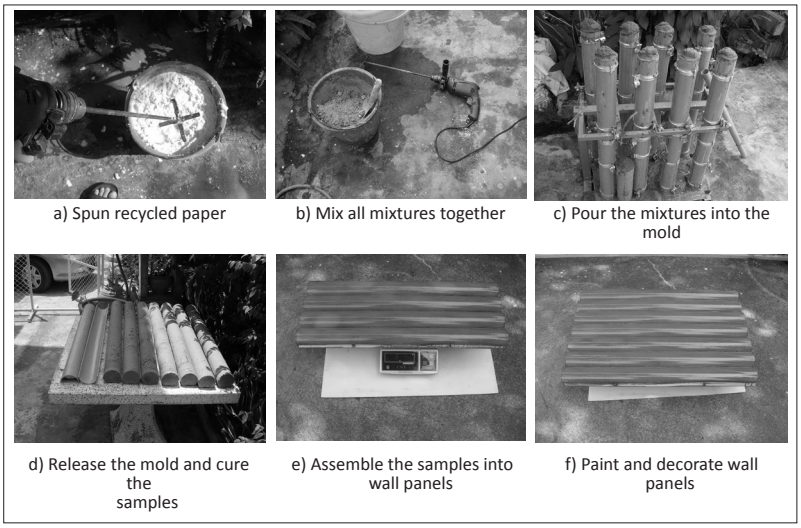


Figure 3. Producing and decorating the prototype artificial log.

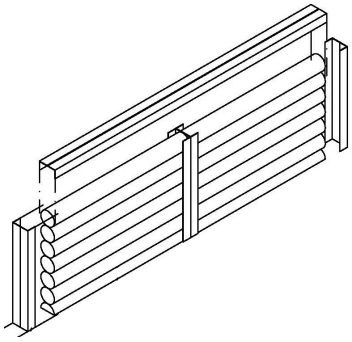


Figure 4. Detail of artificial log wall system.

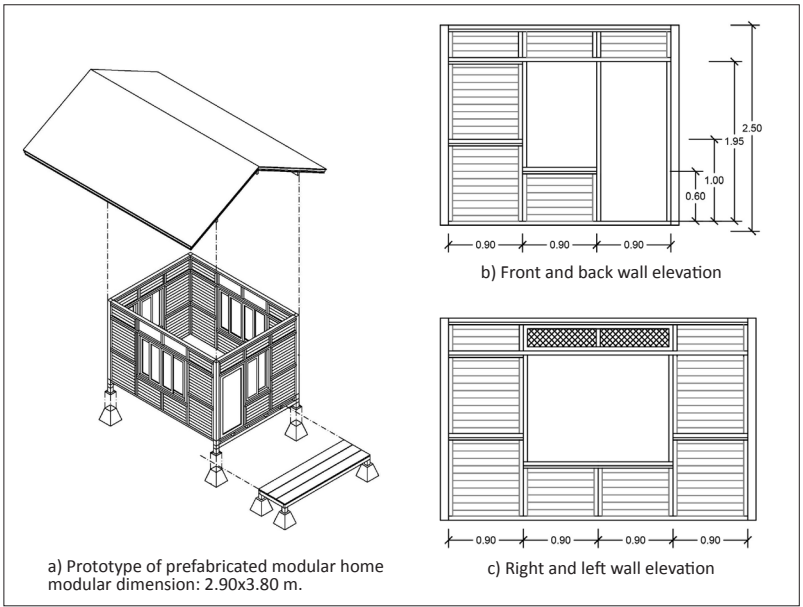


Figure 5. Prototype of prefabricated modular home.

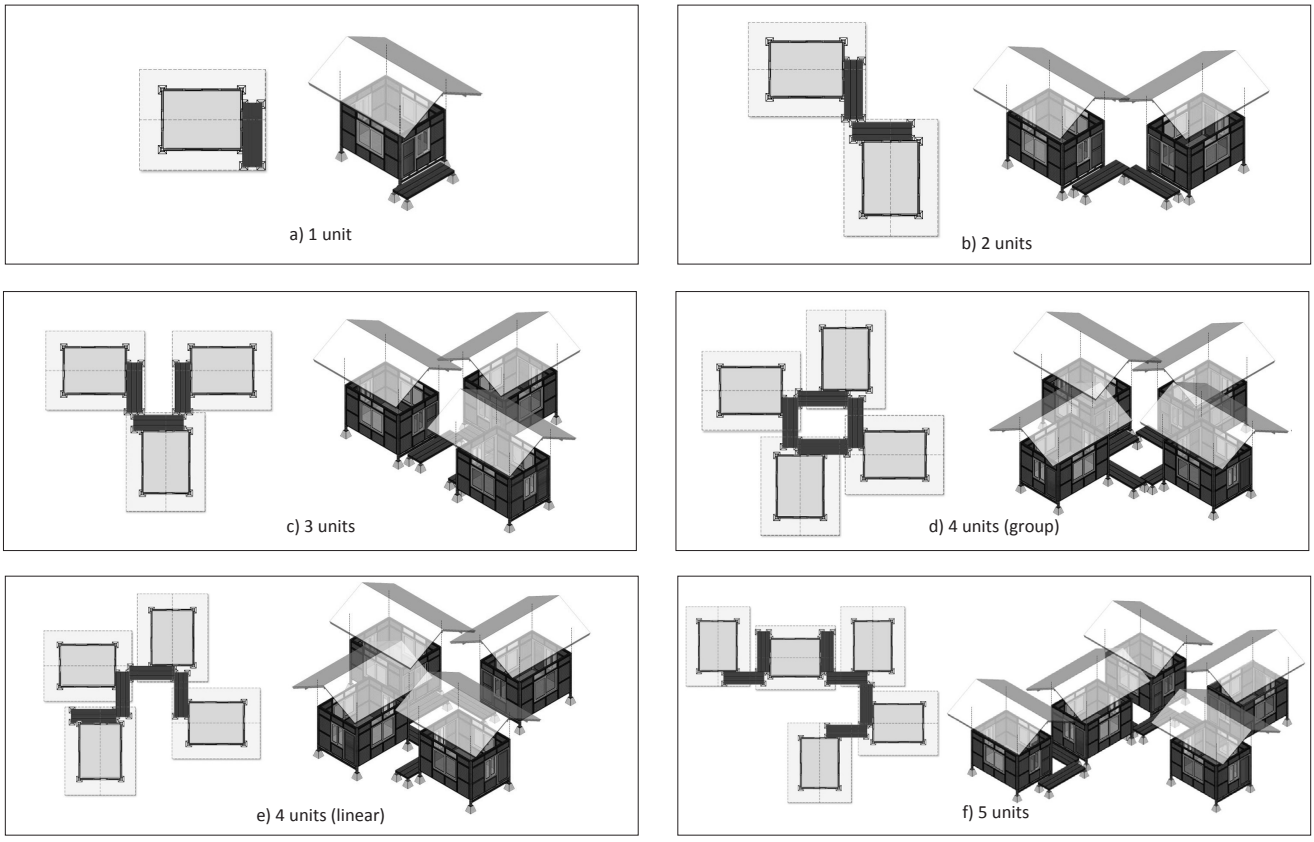


Figure 6. Sample of arranged units for prefabricated modular homes.

This artificial log can be designed and produced with several shapes and dimensions depending on the mold forming. This modular unit can be arranged and grouped into several desired layouts of a prefabricated modular home in Figure 6.

Table 1. All results of the properties of all the specimens.

Properties	Specimen				
	Type 1	Type 2	Type 3	Type 4	Type 5
Density (kg./m^3)	227.4	1393.9	782.4	582.7	1150.0
Weight (kg./m.)	1.14	7.00	3.93	2.93	5.78
Water absorption (%)	1.1	19.5	33.9	34.6	35.0
Compressive strength (kg./cm^2)	34.6	38.9	23.3	30.7	26.2
Material cost (Baht/m.)	100	120	61	76	70

3. Results and Discussion

The results of the all properties of the tested specimens are shown in Table 1.

3.1 Effect of different types of specimens on material density

Figure 7 shows the density of different types of specimens. It was found that Type 1 (PVC pipe) specimen had the lowest density and Type 4 (recycled paper pulp cement reinforced with PVC pipe core) had the second lowest density, indicating that these two types have many areas of air voids in the material. Type 2 (PVC pipe reinforced with recycled paper pulp cement) specimen had the highest density and heaviest weight.

3.2 Effect of the different types of specimens on water absorption

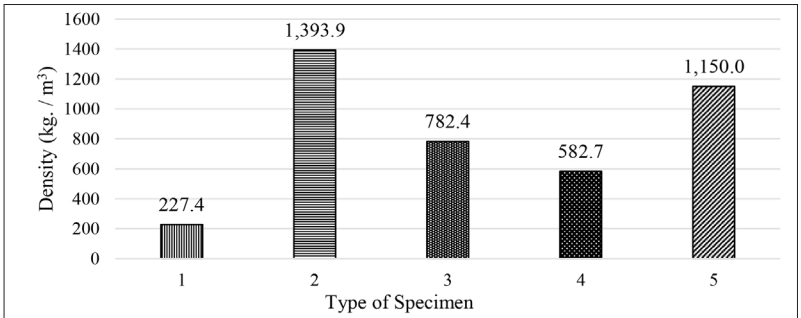
Figure 8 shows the water absorption of the different types of specimens. It was found that Type 1 (PVC pipe) and Type 2 (PVC pipe reinforced with recycled paper pulp cement) specimen had the lowest water absorption respectively, indicating that they have many surfaces of PVC material that can protect against water absorption. Type 3, 4 and 5 specimens had high water absorption, from 33.9 – 35%, indicating the specimen surface should be coated with many layers of water absorption protection.

3.3 Effect of the different types of specimens on compressive strength

Figure 9 shows the compressive strength of the different types of specimens. It was found that Type 2 (PVC pipe reinforced with recycled paper pulp cement) specimen had the highest compressive strength at 38.9 kg/cm^2 and Type 1 (PVC pipe), Type 4 (recycled paper pulp cement reinforced with PVC pipe core) and Type 5 (recycled paper pulp cement reinforced with round bar steel core) specimen passed the Thai Industry Standard of non-load bearing wall block at >25 kg/cm^2. The exception was Type 3 (recycled paper pulp cement reinforced with water plastic bottle core) specimen which was lower than the standard. It may be stabilized with a water bottle size core in the recycled paper pulp cement, so the water plastic bottle core in the recycled paper pulp cement is not stable and strong.

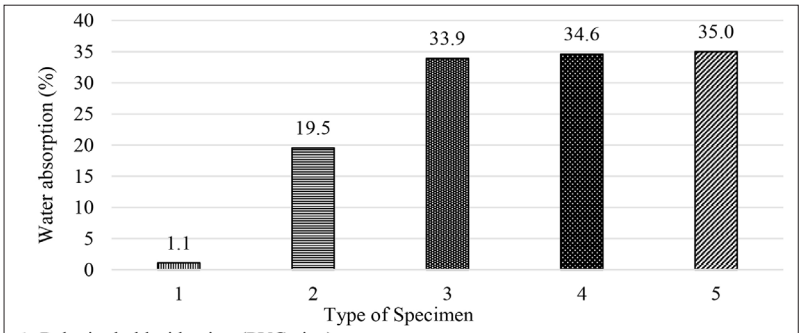
3.4 Material cost of the different types of specimens

Figure 10 shows the material cost per meter of the different types of specimens. It shows that Type 2, Type 1 and Type 4 specimen have the highest cost at 120, 100 and 76 Baht per meter respectively. The recycled paper cement has a lower cost than PVC material.



1. Polyvinyl chloride pipe (PVC pipe)
2. PVC pipe reinforced with recycled paper pulp cement core
3. Recycled paper pulp cement reinforced with water plastic bottle core
4. Recycled paper pulp cement reinforced with PVC pipe core
5. Recycled paper pulp cement reinforced with round bar steel

Figure 7. Density of the different types of specimens.



1. Polyvinyl chloride pipe (PVC pipe)
2. PVC pipe reinforced with recycled paper pulp cement core
3. Recycled paper pulp cement reinforced with water plastic bottle core (coated surface)
4. Recycled paper pulp cement reinforced with PVC pipe core (coated surface)
5.Recycled paper pulp cement reinforced with round bar steel (coated surface)

Figure 8. Water absorption of the different types of specimens.

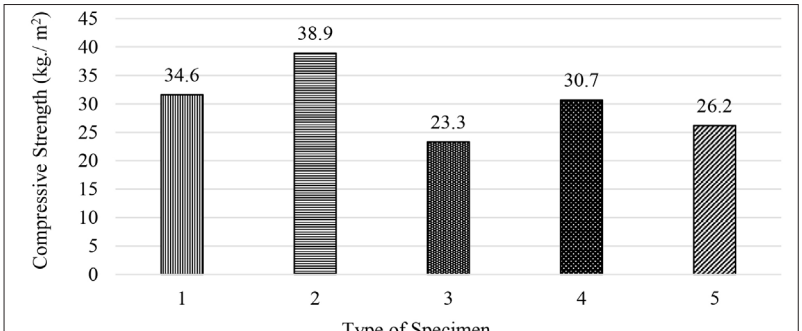


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Figure 9. Compressive strength of the different types of specimens.

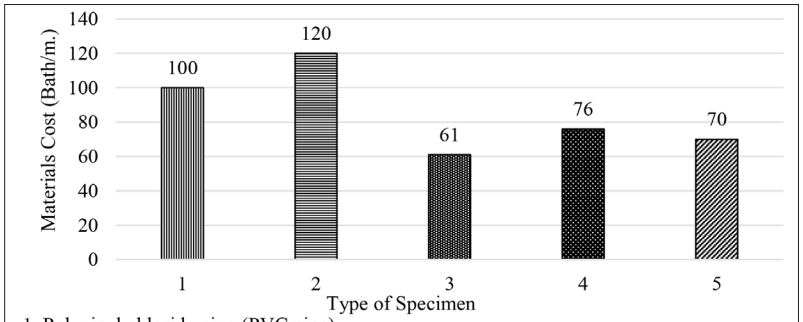

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Figure 10. Material cost of the different types of specimens.

Table 2. Comparison of the properties of the building materials.

Properties	Building materials			
	Clay brick	Hollow core concrete block	Wood log	**Recycled paper pulp cement reinforced with PVC core**
Dimension (cm.)	3.5x16x7	19x39x9	9x100x7.5	**9x100x7.5**
Piece quantity (unit/m^2)	138	13.4	13.4	**13.4**
Weight (kg/unit)	0.07	6.00	1.9	**2.93**
Weight on installation (kg/m^2)	115	82	25.5	**40.0**
Density (kg./m^3)	1800	900	775	**605 ***
Compressive strength (kg./cm^2)	30-40	25-28	-	**30.7**
Water absorption (%)	32	35	15-22	**34**
Thermal conductivity (k) (W/m K)	0.873	0.519	0.18-0.25	**0.35**
R-Value (m^2 °C/w)	0.297	0.355	0.700	**0.386**
Installation (m^2/day)	6-12	18.3	20	**25-28**
Material cost (Baht)	1.0	8.0	350	**25**
Installation Cost (Baht/m^2)	580	560	3,000	**1,210**

Remark: * includes coat materials and steel holder

3.5 Comparison of this artificial log with building materials

When considering low cost, light in weight, low thermal conductivity, low water absorption and high mechanical properties respectively, the artificial log composite from recycled paper pulp cement reinforced with PVC pipe core (Type 4) is selected to produce the prototype of the prefabricated wall panel and assemble the prefabricated modular home. A comparison of the local building materials is shown in Table 2.

When comparing the recycled paper pulp cement reinforced with PVC pipe core with local building materials, it was found that it is light in weight, has good heat protection, and installation is easy and quick, however the material cost is rather high when compared to local bricks and blocks.

3.6 Production process of the prefabricated modular home

From the demonstration, production of this artificial log material and prefabricated modular home found that the recycled paper pulp cement reinforced with PVC pipe core can be produced and assembled as prefabricated wall paper from mold forming by man power and general construction tools.

The main process of the production of the prototype prefabricated modular home at Uthai Thani province is shown in Figure 11. This prototype can be finished in 15 days by the building production of 3 man labor. This building includes 3 components: 1) foot base 2) building body and 3) roof. The function areas of this prefabricated modular home is 14.68 m^2. Balcony area is 3.48 m^2 (2.90x1.20 m.). Indoor function area is 11.02 m^2 (2.90x3.80m.) Total cost is 127,845 Baht with 62,845 Baht in materials costs (49.2%) and 65,000 Baht on labor (50.8%). Its average cost is 11,415 Baht/m^2.

This cost is near the sales cost of local prefabricated home which averages between 12,000-18,000 Baht/m^2. But when all things are considered, this prefabricated home is made of good quality materials and has a stable structure in log style, as shown in Figure 11, more than general prefabricated homes from fiber cement wall in the local market.

4. Conclusion

The results of developing the 5 types of artificial log materials for prefabricated modular home can be concluded as follows:

- All the artificial log materials have very interesting physical and mechanical properties for non-load bearing wall material, except for recycled paper pulp cement reinforced with water bottle core.

1. Prepare land and foot.

2. Install column and beam.

3. Install the wall structure.

4. Insert the artificial log on stud.

5. Hold wall structure.

6. Install roof structure and door.

7. Install ceiling and window.

8. Paint and decorate.

9. Finish

Figure 11. Production process of the prototype prefabricated modular home.

- PVC pipe as artificial log material is very good, light in weight and has good mechanical properties. It can be applied as temporary shelter and building wall.

- Recycled paper pulp cement reinforced with PVC pipe core is low in cost, light in weight, has low thermal conductivity and high mechanical properties.

- This prefabricated artificial log material and new wall system is easy and quick to install and possess good heat protection.

- The prototype prefabricated modular home can be produced within 15 days having function areas that is about 14.68 m^2 with 3 man labors. The average cost is 11,415 Baht/m^2.

Finally, it is a new alternative artificial log material for prefabricated home with log style that saves energy and is environmental friendly for the local industrial home market.

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