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Unfired Bricks Mixed with Para Rubber Latex for Sustainable Construction Materials

Natapong Janpetch [1], Chokchai Trakolkul [1], Itthi Plitsiri [1], Wiphada Thepjunthra [1*]

[1] *Faculty of Engineering and Architecture, Rajamangala University of Technology Suvarnabhumi, Nonthaburi, Thailand*.

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Abstract

This paper aims to study the development of bricks without burning, mixing para rubber latex, and compressing them with the technology of interlocking block production. The ratio of cement, lateritic soil, and water used in the mix was 1:6:11, while the percentage of para rubber latex (PRL) added was 2.5, 5, 7.5, 10, and 12.5% of the cement weight. The optimal PRL content (2.5%–7.5% by cement weight) enhances compressive strength, reduces water absorption, and improves durability, meeting the Thai industrial standard (TIS 77-2545). The PRL7.5 mixture achieved the highest performance, with a compressive strength of 21.42 MPa and a water absorption rate of 7.55%. These advancements are credited to the polymer film network formed from PRL during the hydration process, which strengthens particle bonds and reduces porosity. However, PRL content exceeding 7.5% leads to performance reductions, attributed to thicker polymer films and particle aggregation, which create larger voids within the material. Furthermore, the modified unfired bricks demonstrated enhanced crack resistance, increased ductility, and superior thermal insulation properties. Thermal tests of masonry walls confirmed that unfired bricks provide better thermal insulation. Temperature measurements revealed that houses constructed with unfired bricks consistently maintained cooler indoor temperatures compared to those made with fired bricks, indicating improved thermal efficiency. Environmentally, unfired bricks eliminate carbon emissions from firing processes and offer simpler, more energy-efficient production methods. These bricks provide sustainable alternatives to fired bricks, promoting both environmental and economic benefits for brick-making communities.

Keywords: Unfired Bricks; Masonry Bricks; Thermal Properties; Sustainable Construction Materials.

1. Introduction

The issue of global warming is so significant that nations are increasingly focusing on finding solutions and enhancing greenhouse gas reduction techniques. Currently, Thailand's economic expansion has led to rapid growth and development in the building industry. International Energy Agency (IEA) [1] mentions that the worldwide construction sector annually produces more than 27% of worldwide CO_2 emissions, and combined with the construction material industry, this figure reaches 40%. Greenhouse gas emissions occur in all activities such as production, transportation, and construction [2-4]. Furthermore, an increasing population will inevitably lead to an increase in urbanization, which will quickly increase CO_2 emissions, with the world's energy consumption predicted to double by 2030 [5]. Owing to this issue, the construction industry is shifting towards the use of materials and methods that have a lower environmental impact.

Bricks are one of the most widely used items worldwide for both structural and non-structural elements. The process of making bricks involves combining clay, rice husks, and sand with water, then pressing the mixture put into molds and burning at a high temperature. This combustion process is the main activity that is related to and causes the amount

* Corresponding author: wiphada.t@rmutsb.ac.th

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of carbon to be transferred to the atmosphere. Burnt bricks have been produced commercially in the industry in Thailand for hundreds of years. They can be seen in old temples, pagodas, and city walls. Consequently, brick factories can be observed as a kind of household industry dispersed across the region. The greenhouse effect is a significant issue, and environmental contamination contributes to the towns where brick construction industries are located [6-8].

Using locally available materials and methods in construction is recognized as a key strategy for promoting eco-friendly development. Using eco-friendly materials and waste management techniques is vital to reducing the environmental impact of construction activities [9, 10]. Unfired bricks are a key technological advancement in sustainable materials. Clay materials are locally available, low-cost, and known for their excellent thermal and acoustic properties. Recently, there has been an increasing focus on promoting stabilized compressed earth bricks as environmentally friendly alternatives to conventional construction materials. Notably, the production process eliminates the need for burning, resulting in zero carbon emissions [11-13]. Walker [14] is recommended to use a clay concentration between 5% and 20% to obtain the required compressive strength. However, one of the significant challenges with unfired bricks is their vulnerability to water damage, with potential strength loss of up to 50%, especially when immersed in water. This lack of water resistance remains a critical disadvantage of unfired bricks. To overcome these limitations, the use of stabilizers has been extensively studied, with cement being the most common option. Cement strengthens the soil and improves its water resistance by forming chemical bonds. Muñoz et al. [15] and Abdeldjebar et al. [16] reveal that replacing 12.5%–18% of the soil's dry weight with cement can significantly enhance the mechanical and physical properties of stabilized earth bricks. Besides cement, researchers have investigated the incorporation of latex-based polymeric materials, which exhibit considerable potential for enhancing the durability and flexibility of unfired bricks [17]. Specifically, natural rubber latex (NRL), when combined with cement-stabilized soil, has been shown to enhance compressive strength, permeability, and flexural strength when used at optimal proportions. Similarly, latex-modified concrete has been shown to outperform conventional concrete in terms of durability, bonding, and flexibility, making it a preferred material for structural repairs [18]. Recent studies continue to highlight how innovations such as NRL integration can mitigate the limitations of unfired bricks while advancing sustainability in construction practices.

Thermal insulation plays a crucial role in improving the performance of construction materials, particularly brick wall systems. Alongside the production of environmentally friendly bricks, reducing heat transfer into buildings is essential for mitigating global warming. The use of natural materials to enhance thermal insulation has yielded promising results. Studies on the thermal conductivity of unfired bricks incorporating natural materials report a wide range of values, from 0.2 to 1.2 W/m·K [19]. Among these materials, natural rubber (NR) is considered one of the most effective polymers due to its exceptional mechanical properties, electrical insulation, and high elasticity. Previous research [20-22] has shown that natural rubber and waste rubber exhibit thermal conductivity ranging from 0.14 to 0.863 W/m·K, demonstrating lower thermal conductivity and maintaining effective thermal insulation properties. These characteristics make rubber an excellent material for heat dissipation. For example, Khamput & Suweero [23] found that incorporating vulcanized latex into concrete blocks reduced the testing room temperature by approximately 2°C compared to conventional concrete blocks, aligning with thermal conductivity findings from several studies [20, 24, 25]. Despite these promising results, the use of Para-rubber in wall systems remains relatively underexplored, with limited studies investigating its thermal conductivity. A comprehensive study of the potential and behavior of Para-rubber in modifying unfired bricks is essential, as it could pave the way for the development of more economical and eco-friendly building materials in the future.

This paper investigates the potential of using unfired bricks made with an improved mix proportion and pressing technique, followed by a block interlocking method [26]. Para rubber latex, a locally available material in Thailand, is selected for its stretchiness, flexibility, and waterproof properties [27]. Additionally, it can be mixed with soil and used to prevent water seepage in pond surfaces [28-30]. The enhancement of the bricks' properties is achieved through two potential methods: physical and mechanical stabilization. The paper reports on the compressive strength, moisture content, water absorption rate, thermal insulation, crack patterns, and the ecological and financial advantages of their processing. In conclusion, the properties of the unfired earth bricks are compared with fired bricks, emphasizing the advantages of this production method, including its sustainability and cost-effectiveness.

2. Investigating Brick Construction Applications

2.1. Fired Bricks

Earth bricks have been used for thousands of years. They can be divided into categories by production method. Firstly, handmade bricks refer to bricks that have been hand thrown into sanded molds with no machines used to compact them. They generally lack strength, as they have low tensile strength but compressive strength that is comparatively high, based on the content of the clay, silt, and sand [31]. Second, fired bricks are generally made by a compressing machine or mold. Then, they are cut and dried, then fired in a kiln (open-top) in a controlled temperature environment, as shown in Figure 1.

Figure 1. An open-top kiln

2.2. Unfired Bricks

Generally, unfired clay brick technology involves mixing clay with certain additives to enhance specific properties of the clay bricks. They are compressed in molds and sun-dried to enhance strength and reduce shrinkage. This production presents a sustainable alternative that contributes to the reduction of the environmental impact of dwelling [19]. Table 1 illustrated the advantages and disadvantages of utilizing unfired brick.

Table 1. Advantages and disadvantages of fired and unfired bricks for use in construction [19]

Advantages [32]	Disadvantages [33]
Uses basic tools and low-skilled labor	Lower in durability
Financially advantageous	Increased water absorption
Minimal energy use	Extended construction period
Ecologically sustainable	
Excellent sound insulation	
Excellent fireproof properties	
Easy access to raw materials	
Design-friendly with high visual appeal	

2.3. Research Theoretical of Unfired Bricks

Research into unfired bricks has provided a strong theoretical foundation highlighting their environmental benefits, economic viability, and mechanical performance when compared to traditional fired bricks. Previous studies demonstrated a key aspect of the theoretical framework [19]:

Environmental Sustainability: Unfired bricks are widely recognized for their lower environmental impact because they eliminate the energy-intensive firing process. For instance, their embodied energy is significantly lower than that of fired bricks, reducing carbon emissions and overall environmental costs. Additionally, locally sourced raw materials and other industrial by-products can be integrated into unfired bricks, enhancing sustainability by repurposing waste.

Mechanical and Thermal Properties: Studies have shown that additives such as fibers, lime, fly ash, and natural polymers like para rubber latex can enhance the mechanical properties and durability of unfired bricks. These materials improve compressive strength, water resistance, and thermal insulation. However, excessive use of such additives can reduce strength due to increased porosity [17, 18].

Economic and Practical Benefits: Unfired bricks are cost-effective because they reduce production costs and require fewer resources. For example, using local and easily accessible raw materials decreases transportation costs, while eliminating firing makes the production process faster and more adaptable for rural or small-scale manufacturers. This accessibility has made unfired bricks popular in areas where energy resources or advanced kiln technologies are limited.

Lifecycle and Applications: Unfired bricks are often evaluated using lifecycle assessments, which demonstrate their long-term sustainability. Despite their lower strength compared to fired bricks, they are suitable for low-rise and non-load-bearing constructions, especially in rural or developing regions. Advances in stabilization techniques and additives have expanded their applicability to more demanding environments.

This theoretical foundation demonstrates that unfired bricks align well with goals of sustainable construction and energy efficiency, making them a viable alternative to fired bricks in modern construction practices.

3. Material and Methods

The flow chart was carried out as shown in Figures 2 and 3.

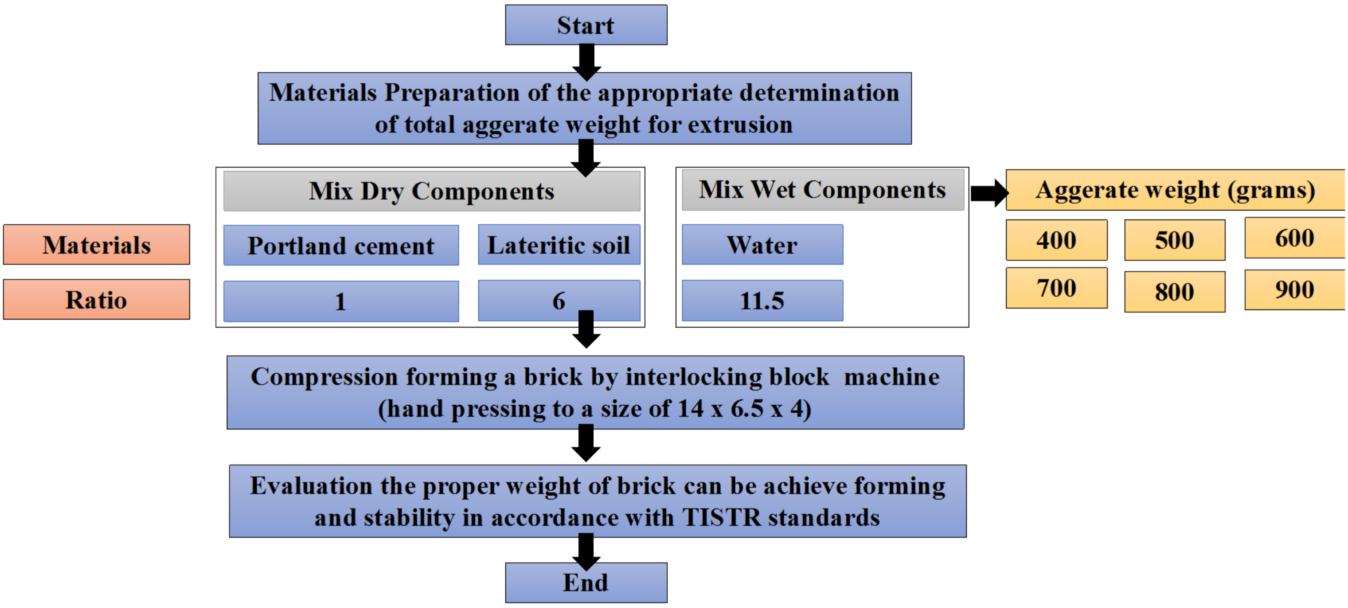


Figure 2. Flow chart of evaluation the proper weight of brick can be achieve forming and stability

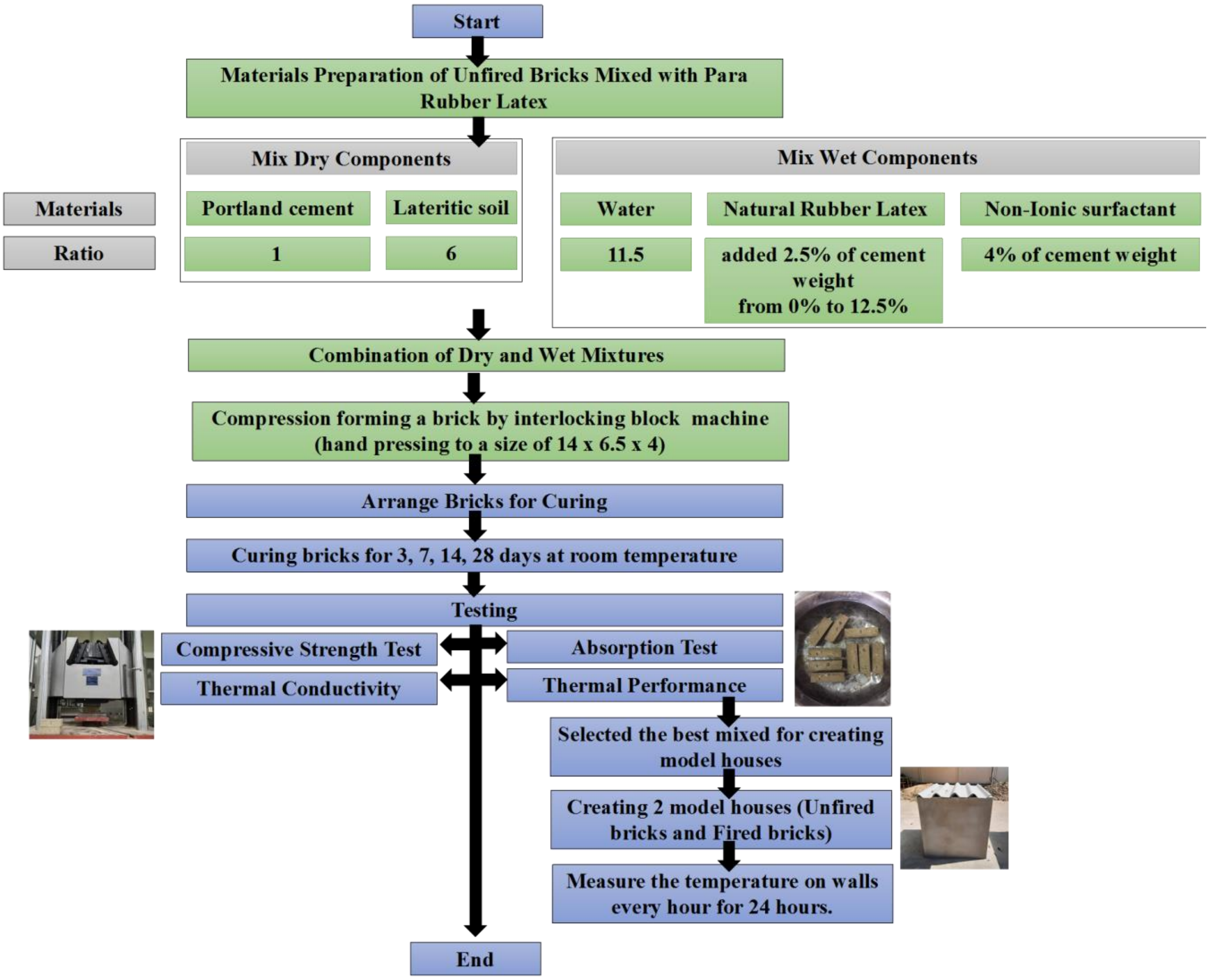


Figure 3. Flow chart of Unfired Bricks Mixed with Para Rubber Latex

3.1. Materials

The materials used consist of lateritic soil, Portland type 1, para rubber latex, and non-ionic surfactant (Teric 320 Stabilizer for NR latex), as illustrated in Figures 4 and 5.

(a) Lateritic soil

(b) Portland cement type 1

Figure 4. Raw Materials

Figure 5. The brick forming machine modified from an interlocking block machine

Lateritic soil is crushed and sieved to the required size. They are classified by AASHTO Soil Classification as A-2-5. Portland cement type 1 meets the requirements of the Thai Industrial Standard TIS 15-2547 (TIS 2004). The primary chemical constituents are calcium oxide (CaO) and silicon dioxide (SiO_2), constituting 65.5% and 21.0%, respectively. [34]. The para rubber latex obtained from H. brasiliensis cannot be used directly due to the inability to control its quality, and it deteriorates rapidly. Thus, an industrial-grade latex was used throughout this research and was vulcanized. Tuffrey et al. [35] demonstrated the formulation shown in Table 2. It consists of 60% high-ammonia natural rubber latex (HA-NRL) as the primary component, along with additives including potassium hydroxide (KOH) and potassium oleate (K-oleate), sulfur, zinc mercaptobenzothiazole (ZMBT), zinc oxide (ZnO), and Wingstay L (an antioxidant). This formulation is provided to enhance the toughness, elasticity, and crack resistance of composite materials, making it suitable for improving the mechanical performance of bricks and other cementitious products.

Table 2. Formulation for PV-NRL compound [35]

Components	Parts by mass (PHR)
60% High-Ammonia Natural Rubber Latex (HA-NRL)	100
50% Sulfur	1.25
50% Zinc Mercaptobenzothiazole (ZMBT)	1.0
50% Zinc Oxide (Zno)	0.4
50% Wingstay L (An Antioxidant)	1.0
20% Potassium Oleate (K Oleate)	0.2
10% Potassium Hydroxide (KOH)	0.2

Non-ionic surfactant has a concentration of 65% and is diluted to 4% to be utilized in para rubber latex.

3.2. Mix Design and Preparation

This research employs interlocking block production technology, as shown in Figure 4. It is based on TISTR, or Thailand Institute of Scientific and Technological Research, TIS. 77-2545 (TIS 2002) [26, 36], to improve clay brick without burning. Bricks are developed to a typical construction size of 14× 6.5×4 cm using the TISTR standard mixture formula of cement and laterite used equal to 1:6 and water used equal to 11.5% of the total mass weight (Cement and Laterite).

3.2.1. Testing for the Appropriate Determination of Total Aggerate Weight

The experiment considered weighing the aggregate material for each brick, starting with 400, 500, 600, 700, 800, and 900 grams for extrusion. The proper amount of weight per block can be evaluated for compression forming and stability in shape in accordance with TISTR, as shown in Table 3.

Table 3. Proportions of mixture designs

Mixed No.	Total Mass Weight	Cement (g.)	Laterite (g.)	Water (g.)
S01	400	57.14	342.86	46
S02	500	71.43	428.57	57.5
S03	600	85.71	514.26	69
S04	700	100	٦00	80.5
S05	800	114.26	٦85.71	92
S06	900	١28.57	771.43	103.5

For the forming compress in the machine, shown in Figure 5, this was modified from an interlocking block machine. It produces six bricks by hand pressing to a size of 14×6.5×4, as illustrated in Figure 6.

Figure 6. The sample of adobe bricks

The para rubber latex is added after determining the proper total aggregate weight in 2.5% of cement, starting with 0%, 2.5%, 5%, 7.5%, 10%, and 12.5%. In general, rubber latex and aggregate combinations are difficult to combine. Therefore, surfactant must be used with 4% of the cement weight. The proportional mixtures are shown in Table 4.

Table 4. Proportions of mix design added with para rubber latex

Mixed No.	Cement: Para Rubber ratio	Cement (g.)	Laterite (g.)	Water (g.)	Rubber Latex (g.)	Surfactant (g.)
PRL 0	1:0	1000	6000	800	0	0
PRL 2.5	1:2.5	1000	6000	791.25	25	40
PRL 5	1:5	1000	6000	782.5	50	40
PRL 7.5	1:7.5	1000	6000	773.75	75	40
PRL 10	1:10	1000	6000	765	100	40
PRL 12.5	1:12.5	1000	6000	756.25	125	40

3.3. Testing Standard

The standards referenced are as follows:

TIS 77-2545 (TIS 2002), or Thai Industrial Standard for Masonry Bricks, specifies the requirements for bricks used in construction, including size, density, compressive strength, and other properties. This standard has been improved following ASTM C216-16, with modifications to the properties of the bricks to align with local usage and environmental conditions in Thailand. There are three standard requirements as shown in Table 5.

- ASTM C1314-18 for Compressive Strength of Masonry Prisms.
- ASTM C138-92 (ASTM 2002) for Density (Unit Weight) of Concrete.
- ASTM C20 (ASTM 2000) for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes.
- ASTM C518 (ASTM 2004) for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus.

Table 5. TIS. 77-2545 (TIS 2002)

Quality Class	Minimum Compressive Strength (MPa)		Maximum Water Absorption rate (%)	
	Prism brick (5 bricks)	Single brick	Prism brick (5 bricks)	Single brick
1. (High Quality Bricks)	21.00	17.00	17.00	20.00
2. (Intermediate Quality Bricks)	17.00	15.00	22.00	25.00
3. (Lower Quality Bricks)	10.00	9	-	-

3.4. Testing

Curing was conducted on the brick samples for 3, 7, 14, and 28 days. The results reported are averages from 5 samples, tested as follows.

The compressive strength of masonry was tested using single and prism specimens according to TIS 77-2545 (TIS 2002) [36], as illustrated in Table 5, and ASTM C1314-18, ASTM C140 [37, 38]. Water absorption and unit weight were measured in accordance with ASTM C20 [39] and ASTM C138-92 [40]. The sample testing setup is illustrated in Figure 7.

a.) Compressive strength test

b.) Water absorption test

Figure 7. The sample testing of adobe bricks

The thermal conductivity coefficients (K) were measured at the Department of Science Service (DSS), Ministry of Higher Education, following ASTM C518 [41]. Furthermore, thermal performance was approximated by creating two model houses and comparing them to different types of bricks. The houses were 1 × 1 × 1 m. in size, with 7.5 cm. thick walls and smooth plaster both inside and out, as shown in Figure 8. Using a variety of clay bricks, including general market clay bricks and unfired clay bricks, measure the temperature on all four external and interior walls every hour for 24 hours.

Figure 8. Two model houses for thermal testing

4. Results and Discussion

4.1. The Proportion of Total Mass Weight and Tolerances of Brick Sizes

Table 6 reveals the testing of each brick's weight proportion and retention abilities. Results showed that a total mass of 400 grams could not be compressed because there was a limited amount of aggregate. However, 500 grams could be formed, but the shape was not preserved. The sample could be achieved at a weight of 600, 700, 800, and 900 grams with a conventional motion without deforming. When measuring the size by a caliper, according to TIS 109-2517 [42], the data was compared to industrial product standards TIS. 77-2545 [36], and the ordinary construction brick standard passed the dimensional tolerance criterion.

Table 6. Results of total aggregate mass per brick

Mixed No.	Total Mass Weight		Physical Characteristics
	Before	After	
S01	400	-	Unable to compress to form bricks.
S02	500	-	Able to form bricks, but not stable
S03	600	597.2	Bricks stable after compacting with higher visible porosity
S04	700	689.6	Bricks stable after compacting with less visible porosity
S05	800	789.1	Ease of compacting, bricks stable with apparent smoothness
S06	900	892	Hardness of compacting, bricks stable and apparent smoothness

4.2. Effect of Compressive Strength and Water Absorption

Figure 9 depicts the results from the compressive strength testing , which shows the tendency in strength to increase for both the curing time and the amount of aggregate material. This is because bricks are pressed by using an interlocking block machine, making it homogenous with cement and water as a binder for the soil. When compacting, minimal voids occurred, showing high strength. On the other hand, for loosely crushed there were numerous voids and the bricks' strength fell as well.

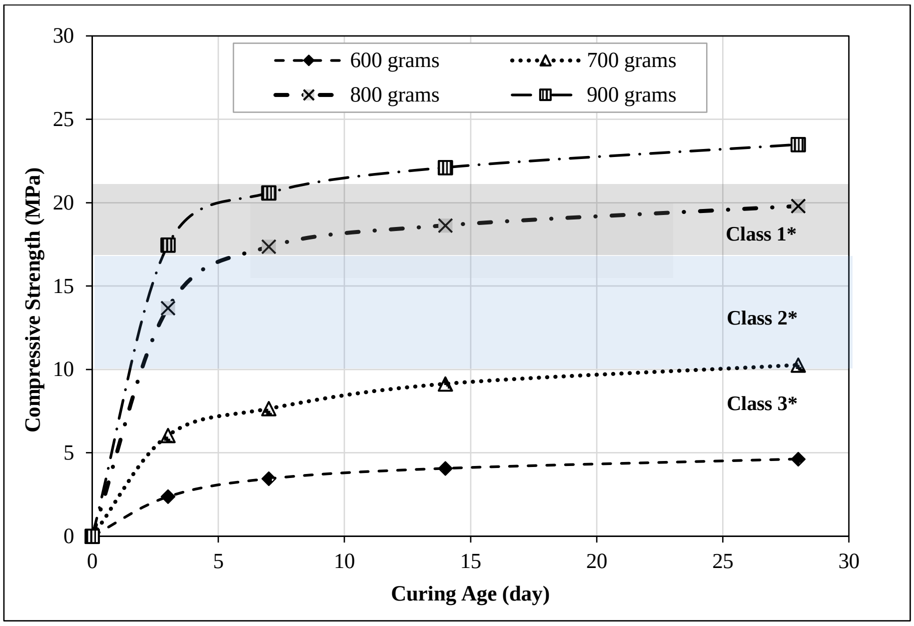


Figure 9. Compressive strength of unfired bricks for each aggregate (Note: *Minimum compressive strength at 28 days curing for class 1, 2, and 3 is 21, 17, and 10 MPa)

The strength values were compared to TIS 77-2002, which has three quality classifications of compressive capability [36], as shown in Table 7. The aggregate weighing of 700 grams at 14 and 28 curing days indicates 9.14 and 10.27 MPa of strength, respectively, passing only in class 3. At curing at 7, 14, and 28 days for 800 and 900 grams, the strength results passed in three classes.

Table 7. Compressive strength compared with TIS. 77-2545 at 28 day curing

Weight of brick (gram)	Dry unit weight (kg/m^3)	Compressive Strength at 28 days (MPa)	TIS. 77-2545 (TIS 2002) (Strength Standard Class)
600	1.473	4.63	Not Pass
700	1.703	10.27	Pass in class 3
800	1.948	19.80	Pass in class 1, 2, 3
900	2.245	23.49	Pass in class 1, 2, 3

The results of water absorption are shown in Figure 10. For the weight groups of 600, 700, 800, and 900 grams, the average water absorption rates at 28 days of curing are 21.9%, 17.5%, 13.19%, and 10.56%, respectively. The rate tended to decrease when the total mass increased, as shown in Figure 10. When compared to TIS 77-2002, it was found that at weights of 700, 800, and 900 grams per brick, each passed quality classes 1, 2, and 3. The rate of water absorption of the bricks is determined mostly by the block's dry density, and as the weight of each brick increases, it correspondingly rises in density. As a result, the water absorption rate decreases.

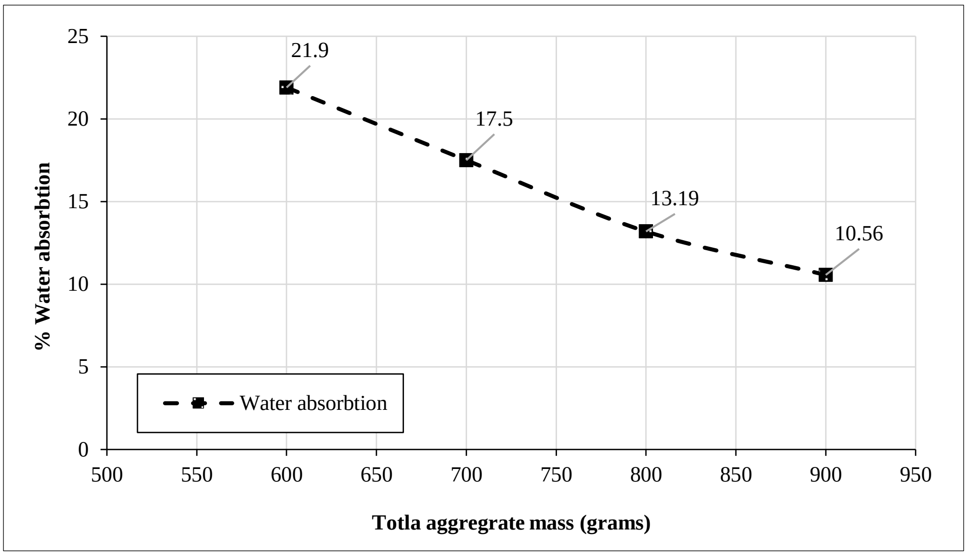


Figure 10. Water absorption of unfired brick each aggregate

According to the results, unfired bricks that were extruded with 800 and 900 grams of aggregate at 3 to 28 curing days were able to acquire compressive strength, average water absorption, and meet standard criteria. This indicates that unfired bricks with applied interlocking blocks technique can be used as a construction material that can minimize production time by avoiding the incineration process. Additionally, when analyzing the ideal weight for extrusion and its ease of use, it was found that 800 grams (a mix of S05) was the optimal weight for producing unfired bricks, which could be combined with latex to enhance their quality.

4.3. Physical and Mechanical Properties of Unfired Brick Mixed Para Rubber Latex

For the preliminary study, the adobe brick that is suitable for mixing and molding is a mixture called S05, which consists of 800 grams of cement, laterite, and water equal to 1:6:11.5% of the total mass. According to research by Khamput [43] and Weeranukul [44], latex is frequently developed as an addition for products that contain cement. When cement and latex react, they mix to form a thin layer that allows for power increases and serves as an effective heat insulator. After, an appropriate aggregate for producing a brick is acquired. Consequently, latex was included as an ingredient, adding 2.5 percent of the cement weight, as illustrated in Table 3. The testing is separated into two groups, including bricks with no latex (control brick, PRL0 mixture) and adobe bricks with para rubber latex (PRL0-12.5 mixture).

Figure 11 indicated the compressive strength increased proportionally with latex content ranging from 2.5 to 7.5 percent by cement weight. They passed the standard for all three quality classes in the Thai standard TIS. 77-2545 (TIS 2002) [36]. The results in the compression strength test conducted on five bricks (solid prism) latex mixes indicate that it followed the same trend as the single brick test, meaning that the strength declined as the rubber ratio increased beyond 7.5%. The ratio mixture between 2.5% to 7.5% met all quality class requirements [33]. For single bricks, the PRL7.5

mixture had higher strength at 28 days of curing, which was 21.42 MPa. It exhibited almost the same strength values at approximately 7.85% of the control brick (PRL0 mixture). However, when the latex content surpassed 7.5% of the cement weight observed in the PRL10 and PRL12.5 mixtures, the strength drastically decreased to 16.21 and 16.16 MPa, which was approximately 18.5% lower than the control brick (PRL0 mixture). These findings indicate that the adding of latex exceeded a limitation for utilization (more than 7.5 percent of cement weight), which caused the strength to decrease.

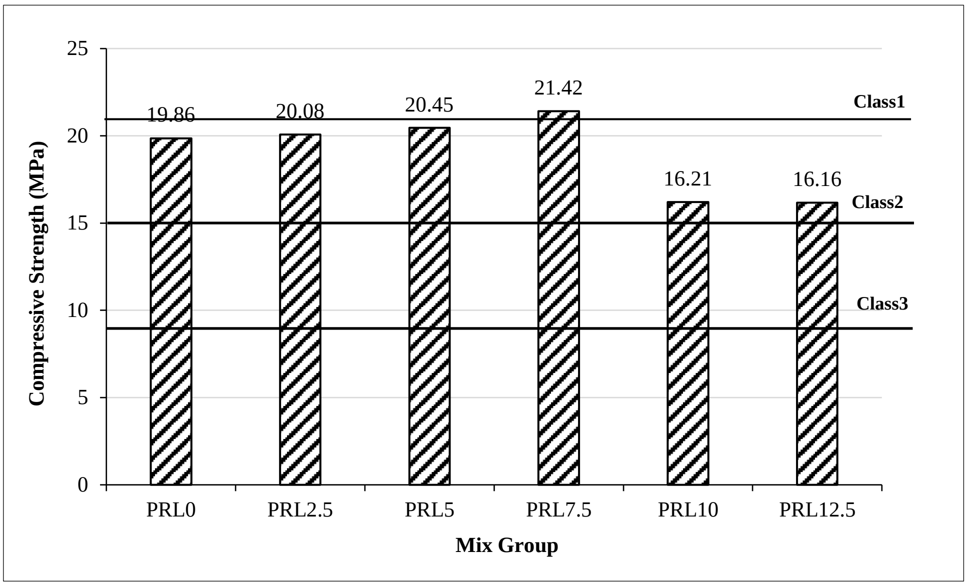


Figure 11. Compressive strength of unfired bricks with added para rubber latex (Single bricks test)

This reduction in strength can be explained by the interaction between the aggregate (lateritic soil) and the binder system. Cement serves as the primary binder, while natural rubber latex is incorporated as an additive. During the hydration process, natural polymer particles from the latex are absorbed and accumulated on the surface of incompletely hydrated cement gel. As hydration progresses, water in the mixture is consumed, and the latex transitions from a liquid state to a solid-state, forming a Polymer Film Network. This network is uniform, elastic, and enhances the binding and confinement ability of the material, contributing to improved strength. Furthermore, the small latex particles infiltrate and fill the micro-pores within the material structure, reducing porosity without disrupting the hydration reaction between cement particles. Consequently, the compressive strength increases with latex content between 2.5% and 7.5%, which is consistent with findings from previous studies [45, 46].

However, when the latex content exceeds 7.5%, the increased thickness of the polymer film surrounding the soil particles begins to weaken the adhesive between particles. Simultaneously, excessive latex content causes particle aggregation, leading to larger clusters and voids within the material structure, as depicted in Figure 12 illustrates the formation of large voids in the PRL10 mixture due to latex clustering, which significantly reduces binding efficiency and results in a noticeable decrease in compressive strength [45].

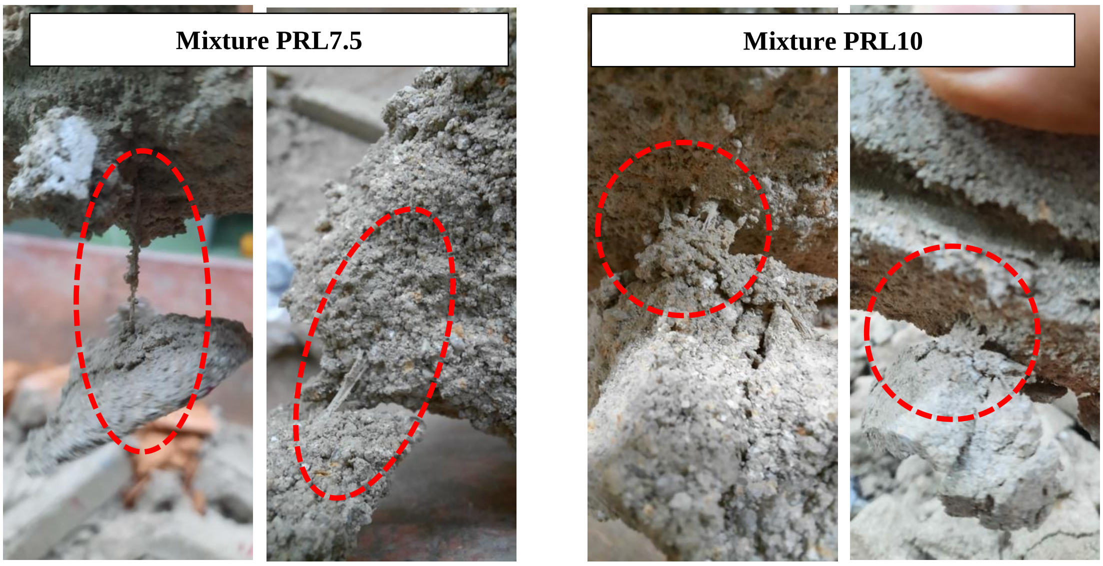


Figure 12. Characteristics of Para rubber latex in bricks after compressive testing

The mixtures PRL2.5, PRL5, PRL7.5, PRL10, and PRL12.5 had water absorption of 8.71, 8.14, 7.55, 7.45, and 7.19, respectively, which exhibited passing in all mixtures of the Thai standard TIS. 77-2545 (TIS 2002), as shown in Figure 13. It can be seen that the rate of water absorption decreased depending on latex content increasing until reaching the limitation of using 7.5 percent of latex, which showed a constant rate after the threshold.

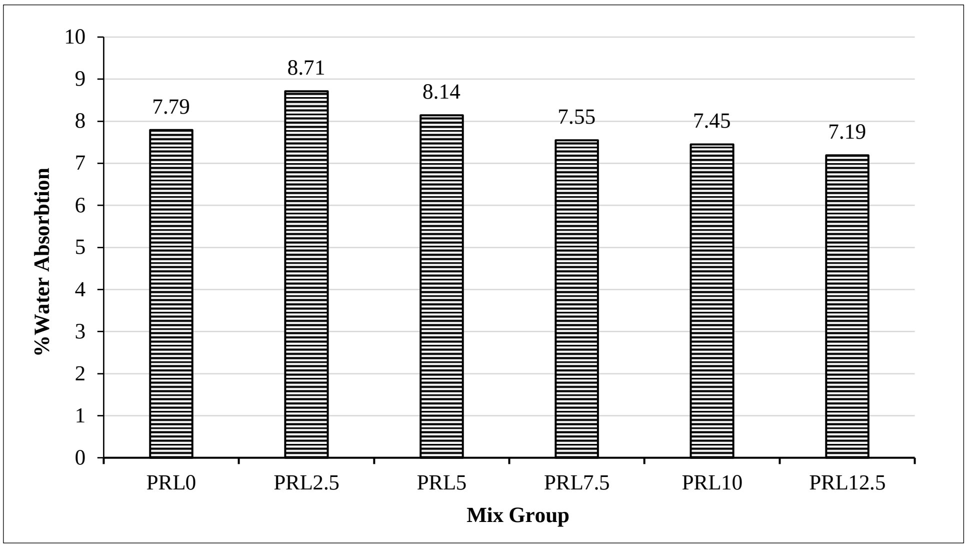


Figure 13. Percentage of water absorption of unfired bricks with added para rubber latex

The mixtures PRL2.5, PRL5, PRL7.5, PRL10, and PRL12.5 had water absorption values of 8.71, 8.14, 7.55, 7.45, and 7.19, respectively, and passed all the Thai standard TIS. 77-2545 (TIS 2002), as shown in Figure 13. It was found that the latex content increased, and the water absorption rate decreased until it reached a limit of 7.5 percent latex, with almost a steady rate after the threshold. According to Wongpa et al. [45] observations, the water permeability coefficient tends to decrease as the para rubber latex percentage increases. This is because the space inside voids is reduced by the latex particle inside of them. However, the addition of more latex resulted in greater voids because the increased latex particle size created a larger void space; therefore, its water permeability increased, which is connected to its compressive strength (see Figure 14).

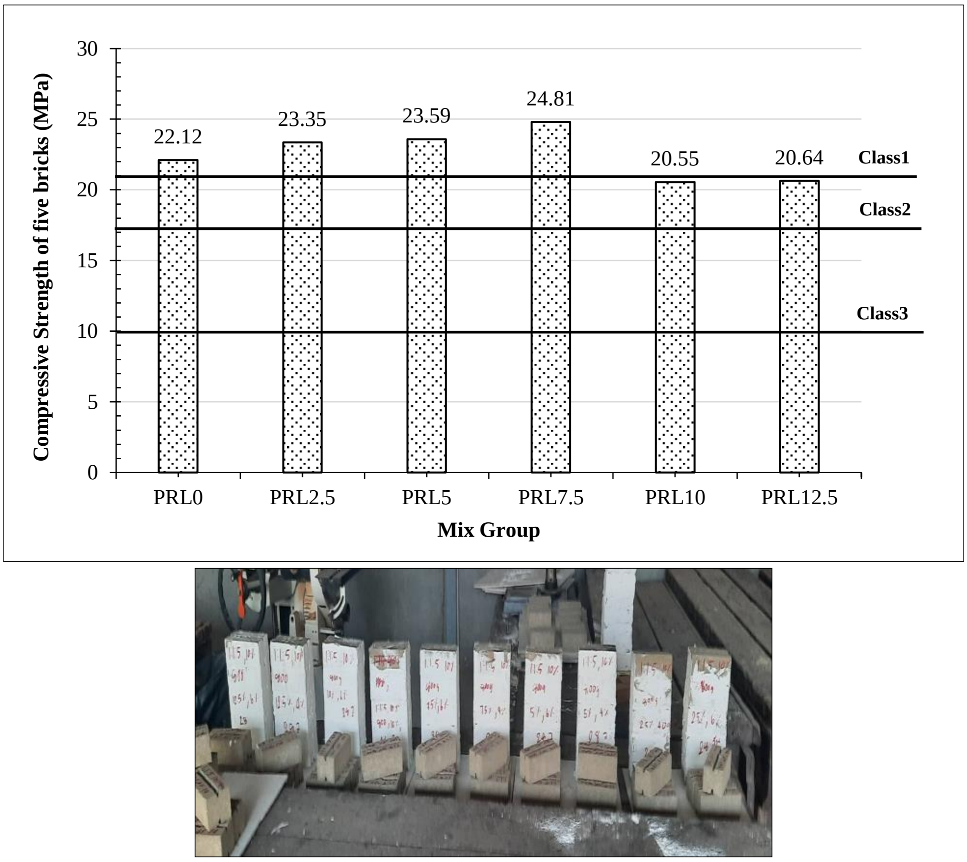


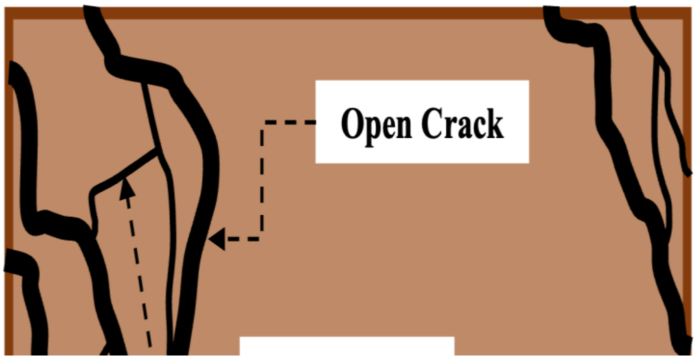
Figure 14. Compressive strength of unfired bricks added with para rubber latex (five brick test or Prism brick test)

4.4. Crack Pattern

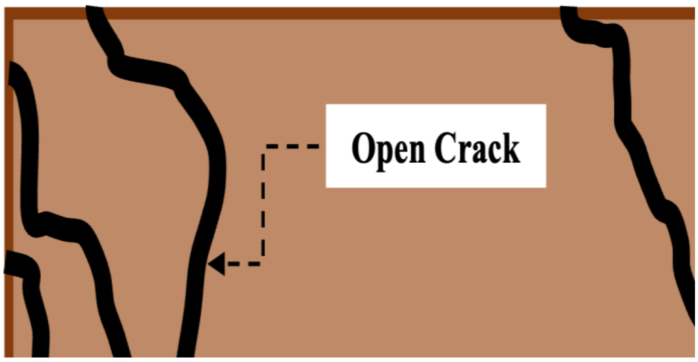
The crack patterns observed in brick samples incorporating natural latex (a natural polymer) resemble those found in polymer-modified concrete. According to Chaikaew et al. [47], the polymer within the cement paste matrix enhances the ductility of the brick specimens. Under compressive loading, micro-cracks begin to form within the material's microstructure and eventually propagate into measurable macro-cracks at failure. In the samples incorporating natural latex, the cracks primarily concentrate on the left and right sides, with fewer penetrating cracks observed in the middle section as illustrated in Figure 15 [48]. Additionally, the cracks in the latex-modified specimens are also more evenly distributed and more numerous. This is attributed to the ductility enhancement provided by the latex, which improves the material's resistance to crack propagation [48, 49].

Figure 15. Crack characteristic of brick mixed para rubber latex

As shown in the crack propagation models in Figure 16, the polymer network formed by the latex improves the ductility of the material under compressive loads [50-52]. These findings are consistent with the internal microstructural features observed post-failure (Figure 16), where fine polymer fibers are visible, forming a binding network between particles in the material. This network reinforces the structure, allowing better performance under compressive forces.



a. Unfired brick mixed with Para rubber latex



b. Unfired brick without natural polymer (Para rubber latex)

Figure 16. Crack propagation in unfired brick

4.5. Effects on Thermal Conductivity of Unfired Bricks

Typically, the firing process of bricks leads to an increase in thermal conductivity (K). Previous studies have indicated that the thermal conductivity of conventional fired bricks is approximately 1.15 W/m·K [53, 54]. K of adobe bricks was tested by the Department of Science Service (DSS), Ministry of Higher Education, in accordance with ASTM C518 [41]. The PRL7.5 mixture testing resulted in K of 0.4271 W/m.K, which is consistent with Ashour et al. [55] and Johra [56], demonstrating that K of unfired bricks has a value from 0.2 to 1.2 W/m.K. When compared to typical fired bricks, the average K value measures 1.15 W/m.K., indicating that adobe without burning provided superior thermal insulation than fired bricks.

As illustrated in Figure 17, the thermal conductivity of the control unfired brick (PRL0 mixture) was measured at 0.4077 W/m·K. This indicates a significantly lower thermal conductivity and superior insulating properties compared to traditional fired bricks. When comparing the control unfired bricks (PRL0) with those modified by incorporating para rubber latex (PRL2.5 to PRL12.5), the variation in thermal conductivity was found to be minimal. Several studies [57-59] have highlighted that the heat transfer properties of bricks are primarily influenced by their porous structure. Highly porous materials can dissipate heat more effectively, thus improving their ability to maintain stable indoor temperatures. In the case of bricks modified with para rubber latex, the formation of a Polymer Film Network during hydration was observed. This network coats soil particles and fills the voids within the pores, creating a thin, flexible polymer film. Consequently, the addition of para rubber latex had no significant effect on the thermal conductivity of the bricks compared to standard unfired bricks.

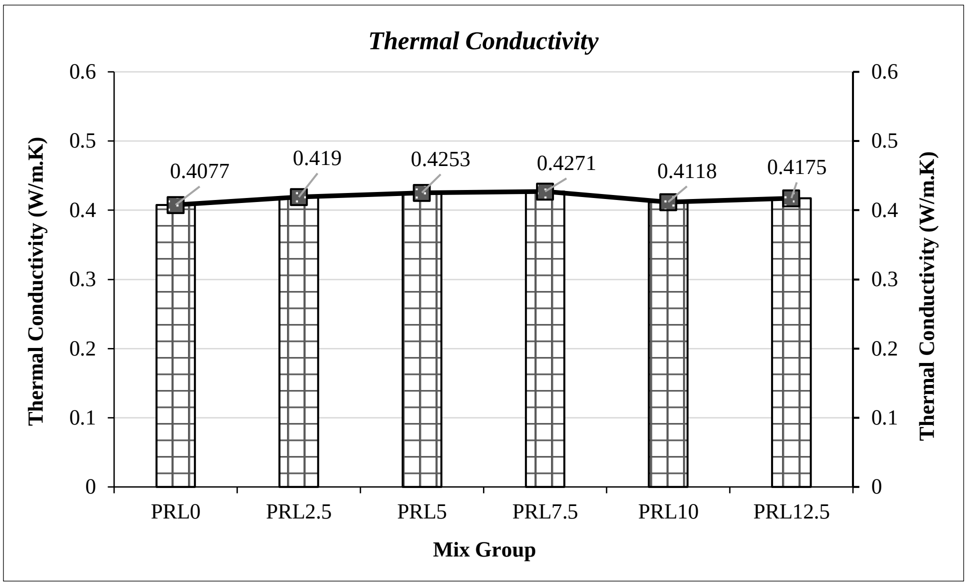


Figure 17. Thermal Conductivity of unfired bricks with added para rubber latex

However, it was noted that when the latex content exceeded 7.5% of the cement weight, there was a slight reduction in thermal conductivity. This was consistent with a corresponding reduction in compressive strength and an increase in water absorption, indicating that excessive latex content may result in void formation within the brick structure. These findings are consistent with Bruno et al. [60], who observed a slight reduction in thermal conductivity when natural rubber was mixed with lateritic soil from different sources.

The thermal performance of a masonry wall was tested by simulating two model houses using different types of construction: fired bricks and unfired bricks, as shown in Figure 8. A thermometer was used to gather data. Data was collected every hour for one day (24 hours a day) by taking temperature readings at five locations on each of the four interior wall surfaces.

The thermal temperature results are depicted in Figure 18. Temperature readings from unfired brick model houses tend to be lower than those from fired brick houses. The temperature was different in the afternoon between 11 am and 8 pm. At 2 pm, unfired and fired bricks had higher temperatures of 37.70 and 39.10 degrees (°C), respectively. This indicates that utilizing unfired bricks as a construction material can limit thermal transmission. This finding corresponded [61] with which evaluated the thermal performance of walls by measuring the heat inside and outside the walls under both winter and summer test conditions. It was shown that the best thermal performance was found in compressed, unfired hollow brick walls, while the poorest performance was observed in fired solid brick walls.

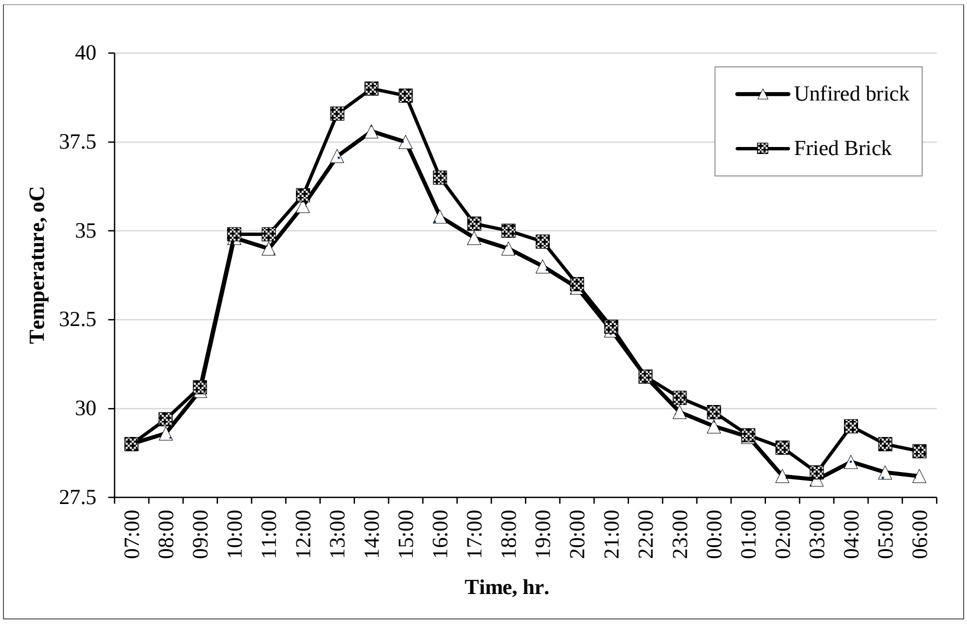


Figure 18. Temperature of model house made by unfired bricks and fired bricks

4.6. Properties of Unfired vs. Fired Brick Products

Table 8 presents a comparison of the properties of fired bricks and unfired bricks, including compressive strength, thermal conductivity, and eco-friendly materials.

Table 8. Comparison of Properties for Unfired Bricks and Fired Bricks

Properties	Unfired Bricks (Mixture no. PRL7.5)	Fired Earth Bricks
Compressive strength (MPa)	21.42	1.5-4
Bricks size (cm.)	(at 28 days curing)	(at 28 days curing)
Weight (kg. Per brick)	6.5×14×4.4	13.5×3×6
Density (kg/m^3)	0.75	0.5
Water absorption (%)	1,871	1,488
Thermal conductivity (W/m.K)	7.55	18-20
Effects on global warming	0.4271	1.15
Average production time (days)	No Effect	Effect

Bricks, which are widely used in building wall construction, are classified from M3.5 to M7.5, corresponding to compressive strength values ranging from 3.5 to 7.5 MPa [62]. The minimum compressive strength that makes unfired clay bricks acceptable for building construction is 3.50 MPa [63]. The test findings showed that the unfired bricks of the PRL7.5 mixture passed the standard criteria. The strength at 28 curing days is 21.42 MPa. In terms of thermal conductivity, unfired clay bricks can dissipate heat more effectively than fired clay bricks. Therefore, they can help to improve the indoor environment.

Considering the effect on the environment, the surveying of local Thai villages with local industrial brick-burning revealed that brick kilns preferred by entrepreneurs are typically rectangular truck kilns, with minor technical advancements, as illustrated in Figures 19 and 20. The resulting issues produce odors and smoke, which have an impact on the community's environment and surrounding places. Each firing of clay bricks lasts roughly 72-78 hours, consumes 10-20 tonnes of biomass fuel, and yields approximately 30,000–50,000 blocks of big bricks. It is the equivalent to the specific energy consumption index (SEC) of 3.6-6.0 megajoules per brick (MJ/Piece) [56]. The exhaust gases and air pollution resulting from the firing of bricks and fuels include carbon dioxide (CO_2), a greenhouse gas that contributes to global warming; sulfur dioxide (SO_2); carbon monoxide (CO); nitrogen oxides (NOx); hydrocarbons (CxHx); volatile organic compounds (VOCs); smoke; and fine particulate matter (PM2.5–PM10).

Figure 19. A surveying of local Thai villages that produce industrial brick burning

Figure 20. Rectangular truck kilns for industrial brick burning in Thai villages

On the other hand, the usage of unburned bricks produces zero direct carbon. It induces carbon indirectly by the transportation process of raw materials to the site, the process of cement production, and so on. In addition, the entire procedure is simple. This can greatly simplify the production process, reducing both the number of steps and the time needed. It has the ability to produce year-round. The study's findings about the non-burning method of producing bricks demonstrate that binders may be mixed into the bricks to maintain their strength and form without the need for burning.

In the hypothetical scenario where half of the current brick production were to shift to unfired bricks for specific applications, producers could reduce their kiln fuel expenses by 325,000 euros and cut carbon tax costs by 87,500 euros each year. Over the course of a decade, these savings would accumulate to more than 4 million euros [19]. This issue requires further future study.

5. Conclusion

This paper studies the effectiveness of incorporating para rubber latex (PRL) as a sustainable additive for enhancing the performance of unfired adobe bricks. Optimal PRL proportions (2.5%–7.5% by cement weight) significantly improve compressive strength, reduce water absorption, and enhance durability, meeting Thai industrial standards (TIS. 77-2545). The PRL7.5 mixture exhibited optimal performance, achieving a compressive strength of 21.42 MPa and a water absorption rate of 7.55%. These improvements are attributed to the polymer film network formed during hydration, which strengthens particle bonds, reduces porosity, and increases water resistance. However, exceeding 7.5% PRL content leads to performance reductions due to thicker films and larger voids.

PRL-modified unfired bricks demonstrate enhanced crack resistance and ductility under compressive loads, with crack patterns resembling those of polymer-modified concrete. Additionally, these bricks exhibit superior thermal insulation properties, with thermal conductivity as low as 0.4077 W/m·K compared to 1.15 W/m·K for fired bricks. Despite minimal changes in thermal conductivity with PRL content up to 7.5%, exceeding this limit slightly reduces thermal performance due to structural changes. The thermal performance testing of masonry walls using both fired and unfired bricks demonstrated that unfired bricks exhibit better thermal insulation properties. Temperature readings from the unfired brick model houses were consistently lower than those from the fired brick houses, especially between 11 am and 8 pm. At 2 pm, the temperature of the unfired brick house was 37.70°C, compared to 39.10°C for the fired brick house. This indicates that unfired bricks can effectively limit thermal transmission, supporting previous studies that showed superior thermal efficiency for unfired materials compared to fired bricks.

Environmentally, unfired bricks eliminate carbon emissions associated with firing and require simpler, shorter production processes, enabling year-round manufacturing. These bricks outperform fired bricks in mechanical, thermal, and eco-friendly aspects, supporting sustainable construction and promoting economic stability for brick-making communities.

6. Declarations

6.1. Author Contributions

Conceptualization, N.J. and W.T.; methodology, N.J. and C.T.; formal analysis, W.T. and I.P.; visualization, W.T. and C.T.; writing—original draft preparation, W.T., N.J., and I.P.; writing—review and editing, N.J., C.T., and W.T.; supervision, N.J.; project administration, W.T.; funding acquisition, N.J. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

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