

INNOVATION OF GREEN CONCRETE ENHANCING PROPERTIES WITH NATURAL RUBBER LATEX, QUARRY DUST, AND CURING TECHNIQUES

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Received: January 08, 2024; Revised: February 27, 2024; Accepted: March 22, 2024

Abstract

This study investigates the development of sustainable cellular lightweight concrete (CLC) by incorporating quarry dust (QD), and natural rubber latex (NRL). CLC, known for its light weightness and thermal insulation, traditionally consumes cement and sand, posing sustainability challenges. NRL, derived from a renewable source, and QD, a by-product, offer eco-friendly alternatives. The study explores the optimal mix proportions of NRL (3%, 5%, and 7% by weight of cement) and the influence of microwave (MW) curing. Results show that 5% of NRL enhances density and compressive strength while reducing water absorption. However, 7% of NRL exhibits trade-offs. QD substitution proved viable, promoting waste reduction. MW curing demonstrates the potential for rapid strength development. The research aligns with industry standards (TIS No.2601-2556) and introduces an environmentally conscious approach to CLC production, fostering sustainability in the construction sector.

Keywords: Cellular lightweight concrete; Microwave curing; Natural rubber latex; Quarry dust

Introduction

Cellular lightweight concrete (CLC) uses preformed foam, in which air-filled voids are created by a suitable foaming agent, in paste, mortar, and cement. CLC is characterized by light weightness, minimal use of aggregate, controlled low strength, and excellent thermal insulation properties. It has a wide density range (400-1,850 kg/m³),

manipulated by proper control of foaming agent dose (foaming agent:water; 1:20-80), useful for application in a variety of construction applications: building structural elements, partition boards, insulation, filling grades, etc. (Amran *et al.*, 2015; Raj *et al.*, 2019). However, the construction industry has been actively pursuing innovative solutions to

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DOI: <https://doi.org/10.55766/sujst-2024-02-e03230>

Suranaree J. Sci. Technol. 31(2):010290(1-9)

develop sustainable building materials for several compelling reasons. The production of conventional CLC consumes cement and sand, which raises concerns regarding energy, environmental, and sustainability aspects, and the need to address the challenges posed by climate change. Therefore, several studies summarized in the recent review by (Shah *et al.*, 2021) reported choices of aggregates that are environmentally friendly, green/bio-materials, and the utilization of waste materials as alternatives to replace the common CLC constituents cement and sand (Thomas, 2018).

Natural rubber latex (NRL) is derived from the latex of the rubber tree (*Hevea brasiliensis*). It is a renewable resource. The production of NRL involves a lower carbon footprint compared to materials like concrete and steel. Using NRL in polymer-modified cement, concrete, and mortar, can contribute to reducing greenhouse gas emissions and mitigate the environmental impacts. Polymers are incorporated widely, at an increasing rate, in civil engineering and other uses as modifiers, especially for improving the general service performances of both cement, concrete, and mortar (Awoyera *et al.*, 2023b; Gerges *et al.*, 2018; Ismail *et al.*, 2011; Muhammad *et al.*, 2011). NRL exhibits excellent flexibility and elasticity, making it suitable for applications where a material needs to withstand deformation or movement, with a high tensile strength, adhesiveness, coating properties, and resilience, as well as abrasion resistance (Yaowarat *et al.*, 2021). Sukmak *et al.* (Sukmak *et al.*, 2020) studied natural rubber-modified cement pastes and reported that the addition of natural rubber can help to improve the flexural strength and toughness of products; moreover, Awoyera *et al.* (Awoyera *et al.*, 2023a) evaluated five loading levels of NRL (0.5%, 1.0%, 1.5%, 2.0%, and 2.5%) in mortar and studied the thermal conductivity, water absorption capacity, and compressive and flexural strengths. The results showed that adding 2.5% NRL to mortar increased its thermal conductivity, but the compressive and flexural strengths of some mixes were degraded.

Quarry dust (QD) is a by-product at about 10–15% of the rocks extracted at quarries, and it could be used to replace sand in the production of concrete and mortar (Lim *et al.*, 2017). QD can now be partially incorporated into concrete, offering a practical application, and its use in construction materials provides an opportunity to utilize a waste material effectively (Febin *et al.*, 2019). By incorporating quarry dust, construction projects can contribute to waste reduction and promote a more sustainable construction industry. Utilizing quarry dust reduces the need for extracting and processing natural aggregates, such as sand and gravel, which can have a significant environmental impact.

Although quarry dust does not possess similar granular shapes as river sand, the other physical and chemical aspects of this alternative seems to be comparable to sand (Ilangovana *et al.*, 2008). Moreover, a high content of quarry dust tends to increase water demand of the mixture, because the large specific surface of fines increases water requirement for maintaining proper workability of the mixture, also resulting in higher shrinkage and strength deterioration during hardening time (Amnon and Hadassa, 2006; Soultana and Galetakis, 2020). Lim *et al.* (Lim *et al.*, 2017) investigated the feasibility of utilizing quarry dust as an alternative to river sand in the production of lightweight foamed concrete (LFC). They found that the use of a large fraction of quarry dust could reduce the fluidity and increase the compressive strength and thermal conductivity of LFC.

Curing plays a vital role in enhancing the compressive strength of mortar and concrete. While the conventional method involves wrapping specimens in plastic and allowing them to harden at room temperature for 28 days, this process is time-consuming. In contrast, modern curing techniques utilize dielectric heating through electromagnetic waves, specifically microwaves within the frequency range of 0.3–30.0 GHz, offering faster and more efficient curing. The heating effect of microwaves (MW) comes from friction forces between molecules as the MW force vibration or rotation of electrically polarized chemical structures. These mechanisms can provide some advantages to MW curing by the volumetric heating inside the material, enabling precisely controlled curing by a uniform supply of heat, and very rapid curing with improved compressive strength of mortar and concrete materials (Makul, 2016; Makul *et al.*, 2017). Jumrat *et al.* (Jumrat *et al.*, 2020) studied the influences of the curing method on the dielectric, thermal, and mechanical properties of geopolymer mortar blended with NRL. They found that MW curing gave superior compressive strength over the other curing methods tested. Manget *et al.* (Mangat *et al.*, 2021) highlighted that MW curing of repair patches offers an energy-efficient method for swiftly repairing concrete. The elevated temperatures induced by MW exposure contribute to accelerated hydration reactions in the cementitious repair materials, enhancing the overall efficiency of the process.

Therefore, this study examined the properties of green cellular lightweight concrete, specifically how they are influenced by a combination of quarry dust and natural rubber latex, exploring the feasibility of producing lightweight concrete that complies with the Thai Industrial Standard (TIS No.2601-2556: Cellular lightweight concrete blocks

using preformed foam, Thai Industrial Standard Institute - TISI, (TIS, 2013). Using QD, a by-product of stone crushing, along with NRL considered a renewable material and MW curing, supports energy conservation and lowering of greenhouse gas emissions, thus enhancing sustainability.

Materials and Methods

Materials

The two tested aggregates were quarry dust (QD) from a Sila-Tong stone mill in Phrasaeng district, Surat-Thani province; and commercial sand sieved through a No. 16 sieve to achieve a uniform maximum particle size. Portland Cement Type-I was used as a fundamental ingredient in the cellular lightweight concrete (CLC). Natural rubber latex (NRL) with a 60% solids content (Huang *et al.*, 2018) was obtained in high-ammonia grade, provided by the Thai Rubber Latex Group Public Company Ltd., Surat Thani province. A foaming agent, which is a chemical reagent containing sodium laureth sulphate that facilitates the formation of foam as 1:20 (agent:water) aqueous solution, was used to incur a cellular structure in the CLC. The water-reducing agent, also known as a plasticizer, is a chemical admixture added to concrete to boost workability and decrease the water to cement ratio, improving its performance. It was mixed to enhance workability and allow reducing the water-to-cement ratio. Finally, the surfactant sodium lauryl sulfate (SLS) was used to stabilize the foam formed during aeration.

Preparation of the cellular lightweight concrete samples

The proportions of cellular lightweight concrete (CLC) mixes used in this study, incorporating quarry dust (QD; LCQD), natural rubber latex (NRL; LCQD+NRL), are presented in Table 1.

Cement, sand, and quarry dust (QD) were placed into a Hobart mixer having a paddle speed of 285 ± 10 revolutions per minute (rpm). The

ingredients were mixed for 2 min until well combined. Then the water-reducing agent was added. The cement, sand, and QD were mixed together, adding the water to the mixer, and the ingredients were blended for an additional 2 minutes until thoroughly mixed. Afterward, sodium lauryl sulfate (SLS) surfactant with natural rubber latex (NRL) was added ensuring a homogeneous mixture, and this mixture was added into the mixer with mixing continued for 2 min. Once all the components were well combined, the concrete foam was produced using a foam generator (Zhengzhou Lead Equipment Co., Ltd. Model LR5) integrated in the mixer, and mixed for another 2 min. The mixture yields were obtained for the CLC samples, which included QD and NRL. It should be noted that the CLC samples at this stage were called “freshly mixed CLC samples” and they were tested for flowability expressed as a percentage, indicating the amount of water that enables the mixture to be in a fluid state and attain formability. For this test, the flow table was designed to test the spreading flow of lightweight concrete according to ASTM C230/C230M-14 (ASTM, 2020).

For casting, the fresh CLC was poured into a cube-shaped mold of $5.0 \times 5.0 \times 5.0$ cm size. The mold was then left at room temperature until the sample had solidified (24 hours). Afterward, the sample was removed from the mold.

Curing methods

After the CLC samples were removed from their cube-shaped molds, the alternative curing methods were tested for their effects. In one method, the samples were wrapped in vinyl-plastic sheets (VPS) to prevent the loss of moisture and were then kept at ambient room temperature for 28 days. The other method was to cure the samples under microwave energy (MW) supplied at 2.45GHz, 450 W for 3 minutes (Jumrat *et al.*, 2020) and then to keep them at ambient temperature for 28 days. It should be noted that all the cured samples were kept at ambient room temperature for 28 days of hardening time before testing; the 28-day strength is a standard measure used to characterize the quality of cement mortar.

Table 1 Mixture proportions of cellular lightweight concrete (CLC) samples.

Specimen Series	Mixture content of lightweight concrete per batch (g)						
	Water	Cement	Sand	QD	Solids amount /equivalent NRL	SLS	Water-reducing agent
Control	366.81	643.53	1029.65	0	0/0	0	1.84
LCQD	377.30	639.50	511.60	511.60	0/0	0	1.83
LCQD+NRL ₃	373.79	633.54	506.83	506.83	19.01/31.68	0.95	1.81
LCQD+NRL ₅	371.48	629.63	503.70	503.70	31.48/52.47	1.57	1.80
LCQD+NRL ₇	369.20	625.77	500.61	500.61	43.80/73.01	2.19	1.79

We note that for concrete, it has been common to test the 3, 7, and 28-day strengths. These support, in the same order, removing the mold, gentle use, and reaching the nominal design strength for full use. The last one is the most important as it potentially prohibits some applications, while the early strength supports less critical aspects that contribute to convenience.

Properties of the cellular lightweight concrete

After curing and aging processes, the cellular lightweight concrete (CLC) samples were studied for their properties dependence on the mixture proportions in Table 1.

Density

The CLC samples were weighed and their dimensions were measured to calculate the density as follows:

$$\rho = \frac{m}{V} \quad (1)$$

where ρ is the density (kg/m^3), m is the weight of the cube-shaped CLC sample (kg), and V is its volume (m^3).

Water Absorption (%)

The percentage of water absorption (WA%) was tested according to an industry standard (ASTM C:426-70 and TIS No. 49-2516) for the hardened CLC samples. This involved immersing the sample cubes in water for 24 hours and the difference in weight before and after immersion gave the absorbed water amount. Therefore the percentage was:

$$WA\% = \frac{W_2 - W_1}{W_1} \times 100 \quad (2)$$

where W_1 is the weight of the CLC sample cube before immersion (g), and W_2 is the weight of the CLC sample cube after immersion (g).

Compressive Strength

Finally, all the cured CLC samples at the age of 28 days were subjected to compressive strength testing according to ASTM C109 standard for testing cement mortar, using the THAITHAMRONG compression testing machine, model KC-2000.

Predictive model fits

In this section, all the data from the two curing methods: vinyl-plastic sheet (VPS) and microwave energy (MW) were used to train models by using the Regression Learner Application in MATLAB® software. This application trains regression models

to fit the data, automatically searching for the best regression model type among linear regression models, regression trees, Gaussian process regression models, support vector machines, efficiently trained linear regression models, kernel approximation models, ensembles of regression trees, and neural network regression models. In this study, the set of input data (predictors) or the observation data set consisted of quantity in grams of water, cement, sand, quarry dust (QD), and solids content of natural rubber latex (NRL); while the response variable or dependent variable of the models was compressive strength. Finally, the different models were compared based on distances between the model fit values and the observed values via the root mean square error (RMSE) summarizing these distances, as a measure of how wide the spread of these residuals was. Moreover, the coefficient of determination (R^2), which is always smaller than 1 and usually larger than 0, was also used to compare the trained models. For the best fit of the data by a model, one would want the lowest RMSE and the R^2 closest to 1. The RMSE and R^2 are expressed by equations as follows (Hilloulin and Tran, 2022; Miao *et al.*, 2023).

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (sim_i - exp_i)^2} \quad (3)$$

$$R^2 = \frac{\sum_{i=1}^N (exp_i - \bar{exp})(sim_i - \bar{sim})}{\sqrt{\sum_{i=1}^N (exp_i - \bar{exp})^2 \sum_{i=1}^N (sim_i - \bar{sim})^2}} \quad (4)$$

where exp_i is the experimental value of i -th sample point in the database, sim_i is the output made by a fitted machine learning model for the i -th sample point, $\bar{exp}$ is the average experimental value, and $\bar{sim}$ is the mean model output value.

Results and Discussion

This study investigated the influences of the quantity of natural rubber latex and the choice of curing conditions on the properties of lightweight concrete, made with quarry dust included, both in the fresh state and the hardened state. The experimental results are now presented in detail.

Flow characteristics

The flowability of cellular lightweight concrete (CLC) samples, when studied in the fresh state, can be indicated by the percentage of flow according to the standard (ASTM C1437), which represents the amount of water required to maintain the mix in a fluid state for molding. From the test results, it was found that increasing the proportion

of natural rubber latex (NRL) resulted in higher water demand by the CLC samples. It's common for flow to increase with higher water content. Therefore, if a mix requires a significant amount of water to flow, it indicates poor flowability. The results are demonstrated graphically in Figure. 1.

From the study on the influence of NRL content on the properties of CLC mixed with aggregate, it was found that an increase in the amount of natural rubber latex resulted in higher water demand for CLC. This is because when NRL was mixed with concrete, two reactions occurred: the first is the hydration reaction that takes place between cement and water, and the second is the coalescence reaction that forms a film of the polymer on particles, which acts as a binder between the aggregates and the concrete (Kujawa *et al.*, 2021). This causes the CLC to have an increased water demand.

Properties of hardened cellular lightweight concrete

The experimental results for the hardened cellular lightweight concrete (CLC) samples (density, %water absorption, and compressive strength) were analyzed using analysis of variance (ANOVA) to determine if the differences in means were statistically significant at 95% confidence level (P-value < 0.05 threshold). Significantly different treatments are indicated by different letters in the bar graphs, while the same letter shows that no significant difference was found.

Density

According to a relevant standard, the CLC is required to have a density in the range of 501 to 1,600 kg/m³ (Industrial Product Standard TIS No. 2601-2556). After analyzing statistically the results obtained from experiments with the two curing methods (VPS and MW), it was found that the range of average density was from 998±45 to 1,468±36 kg/m³. Considering the influence of the quantity of NRL on the density of hardened CLC samples aged for 28 days and cured with a vinyl-plastic sheet (VPS), it was observed that the average density of the CLC mix with 3% NRL (LCQD+NRL₃) did not significantly differ from the mix with 5% NRL (LCQD+NRL₅). Likewise, the average density of the mix with 3% NRL (LCQD+NRL₃) did not significantly differ from the mix with 7% NRL (LCQD+NRL₇). However, significant differences in mean density were observed in the other comparisons, as shown in Figure 2. Furthermore, considering curing with microwave energy (MW), it was observed that the density of the CLC mixes with 3% NRL (LCQD+NRL₃) did not significantly differ from the mix with 7% NRL (LCQD+NRL₇).

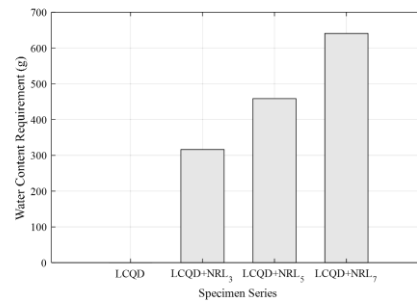


Figure 1. The additional amount of water that was required to achieve the desired percentage of flow for CLC samples, according to ASTM C1437 standard

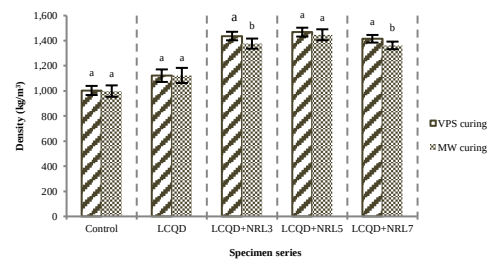


Figure 2. The average densities of all the specimen series at 28 days of age, when cured with vinyl-plastic sheet (VPS) or with microwave energy (MW)

Similarly, significant differences in mean density were observed in the other comparisons, as shown in Figure. 2. When considering the curing conditions' influence on the density of lightweight concrete mixtures with natural rubber latex and fine aggregates at 28 days of age, it was found that only the mixtures LCQD+NRL₃ (with 3% natural rubber latex) and LCQD+NRL₇ (with 7% natural rubber latex) exhibited statistically significant differences in average density between the alternative curing approaches, as reported by (Jumrat *et al.*, 2020). For the other mixtures, there were no statistically significant differences in average density between the two curing conditions as shown in Figure. 2.

Water absorption (%)

The standard specifies that cellular lightweight concrete (CLC) should have a percentage of water absorption (WA%) not exceeding the limit that ranges from 20% to 25% (Industrial Product Standard, TIS No. 2601-2556). After analyzing statistically the experimental data for the two curing methods (VPS and MW), it was found that the average range of WA% was from 3.15±1.71% to 9.24±0.15%. Considering the influence of the amount of NRL on the WA% of CLC mixtures with

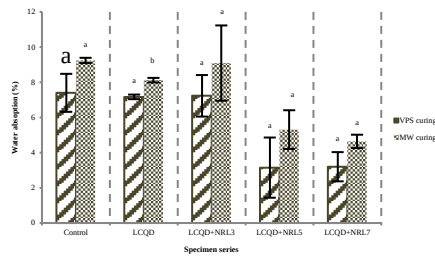


Figure 3. The average percentage of water absorption (WA%) for all the specimen series at 28 days of age, when cured under vinyl-plastic sheet (VPS) or with microwave energy (MW)

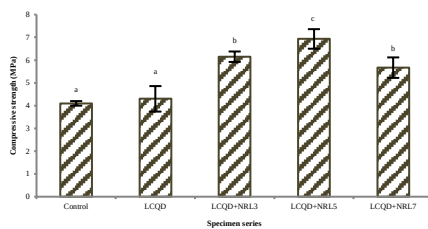


Figure 4. The average compressive strengths of all the specimen series at 28 days of age, when cured under a vinyl-plastic sheet (VPS)

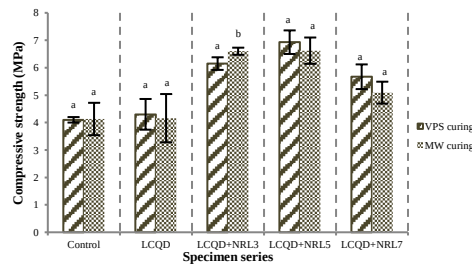


Figure 5. The average compressive strengths of all the specimen series at 28 days of age, cured under vinyl-plastic sheet (VPS) or with microwave energy (MW).

fine aggregates at 28 days of age and cured with a vinyl-plastic sheet (VPS), it was observed that the control mixture without NRL (Control) had no significantly different average WA% compared to the mixture without NRL but with fine aggregates (LCQD). It was also similar to the mixture with 3% of NRL (LCQD+NRL3), which had an average WA% that differed significantly from the mixture with 5% of NRL (LCQD+NRL5) and from the mixture with 7% of NRL (LCQD+NRL7). Moreover, all other comparisons showed statistically significant differences in the average WA%. These findings are presented in Figure. 3. Regarding the cases cured with microwave energy (MW), it was found that the mixture with 3% of

NRL (LCQD+NRL3) had a significantly different average WA% compared to the mixture with 5% of NRL (LCQD+NRL5) and also differed significantly from the mixture with 7% of NRL (LCQD+NRL7). Additionally, both of these mixtures had a significantly different average WA% from the mixture without NRL but with fine aggregates (LCQD). Furthermore, all the other comparisons showed statistically significant differences in the average WA% rates, as illustrated in Figure. 3.

Compressive strength

The compressive strength of CLC is classified by bulk density into 8 categories, among which C6-C8 requires 2.0 MPa, C9-C12 requires 2.5 MPa, and C14-C16 requires 5.0 MPa according to TIS No. 2601-2566 (TIS, 2013). After analyzing statistically the results from the experiments, it was found that the average range was from 4.10\pm0.10 MPa to 6.93\pm0.43 MPa. Considering the influence of the amount of NRL on the compressive strength of CLC containing quarry dust (QD) at 28 days of age, when cured covered with a vinyl-plastic sheet (VPS), it was observed that the control mixture without adding NRL (Control) had an average compressive strength similar to the CLC mixture mixed with QD but without adding NRL (LCQD). The CLC mixture mixed with QD and with 3% of NRL (LCQD+NRL3) had an average compressive strength similar to the mixture with 7% of NRL (LCQD+NRL7), while the other specimen series show statistically significant differences in compressive strength. These findings are presented in Figure. 4.

In the microwave-cured cases, it was found that the CLC mixed with QD but without adding NRL (LCQD) has an average compressive strength similar to the mixture with 7% of NRL (LCQD+NRL7). Both of these mixtures also have average compressive strengths similar to the control mixture without adding NRL (Control). The CLC mixture with 3% of NRL (LCQD+NRL3) had an average compressive strength similar to the mixture with 5% of NRL (LCQD+NRL5). The other comparisons of the concrete mixtures exhibit statistically significant differences in the average compressive strength, as shown in Figure. 5. When considering the curing conditions' influence on the average compressive strength of CLC mixed with NRL and QD at 28 days of age, it was found that only the mixture with 3% of NRL (LCQD+NRL3) exhibited a significant difference in average compressive strength between the two alternative curing conditions. As for the other mixtures, there was no significant difference in average compressive strength between the two curing conditions. This is shown in Figure. 5.

Based on the results of the study on the influence of the amount of NRL on the properties of 28-day hardened CLC mixed with aggregate, it was found that the VPS was suitable for curing the CLC samples, particularly the one with 5% of NRL content (LCQD+NRL5). This sample complied with the specified standard (TIS No. 2601-2556) and was classified as lightweight concrete grade C16. It had the highest average compressive strength of 6.93 ± 0.43 MPa, the lowest average water absorption rate of $3.2 \pm 1.7\%$, and an average density of $1,470 \pm 36$ kg/m³. In a prior study (He *et al.*, 2016), they modified the rubber surface by introducing strong polarity groups to create a robust chemical bond between the rubber and cement matrix. They observed that this surface modification significantly improved the compressive strength of rubber-cement concrete during mechanical testing. On the other hand, among the cases cured with MW, the most suitable sample in this study was also the one with 5% of NRL (LCQD+NRL5). Similarly, it complied with the specified standard (TIS No. 2601-2556) and was classified as CLC grade C16. It had the highest average compressive strength of 6.6 ± 0.5 MPa, the lowest average water absorption rate of $5.3 \pm 1.1\%$, and an average density of $1,450 \pm 44$ kg/m³. These findings are consistent with previous research that suggested using NRL to enhance the properties of CLC with air-entrained and steam-cured foaming, where the addition of NRL reduced the water absorption rate. This is due to the film layer acting as a binder material, resulting in increased density, reducing air voids, and decreasing permeability to water. The amount of NRL also had an impact on the development of the compressive strength of CLC. However, an excessive content of NRL could decrease the compressive strength (Yaowarat *et al.*, 2021).

The study examined how curing conditions affect the properties of CLC when mixed with NRL and aggregate and cured for 28 days. It was discovered that the most suitable condition was using a vinyl-plastic sheet to cover the samples. The plastic sheet reduced water loss through evaporation, maintaining the concrete's moisture and temperature levels. This enabled continuous and complete cement hydration, resulting in reduced cracking, increased compressive strength, and enhanced durability. In contrast, when microwave energy was used for curing, it caused the internal temperature to rise with heat transfer from the interior to the surface of the material. This rapid heating led to the quick evaporation of moisture inside the material, potentially hindering complete cement hydration. This aligns with research on the behavior of fly ash cement mixed with pozzolan

material when cured with microwave energy (Chatveera and Homsriprasert, 2011). It is essential to consider the maximum temperature generated during hydration to avoid excessive heating, which could damage the chemical bonds and make the material brittle. Additionally, the formation of high-pressure water vapor due to heating may reduce compressive strength (Chatveera and Homsriprasert, 2011). Finally, when compared to the industrial product standard (TIS No. 2601-2013), the studied samples can be classified as follows: lightweight concrete cured with a plastic film, with 3% natural rubber latex; lightweight concrete cured with a plastic film, with 5% natural rubber latex; and lightweight concrete cured with a plastic film, with 7% natural rubber latex, can all be classified as C16 grade lightweight concrete. As for the samples cured with microwave energy, lightweight concrete with 5% natural rubber latex falls under C16 grade, while lightweight concrete with 3% and 7% natural rubber latex fall under C14 grade. The green cellular lightweight concrete (GCLC) production with refined sand, quarry dust, and blended with NRL was compared to the previous study by (Lim *et al.*, 2017), which was based on the standardized life cycle assessment (LCA) methods. This study on the GCLCs indicated about 7% and 10% lower greenhouse gas emissions associated with the innovative products.

Model fitting results

The experimental results had 15 records per curing method: vinyl-plastic sheet (VPS) and microwave energy (MW). Five-fold cross-validation was used to protect against overfitting, by partitioning the data set into folds, and estimating the accuracy on each fold when the model is fit to the other remaining folds. The best cross-validated prediction performance for VPS curing was by the Fine Gaussian support vector machine (SVM) with Gaussian kernel function and 0.50 kernel scale. This one had RMSE=0.46 and $R^2=0.85$. In the case of MW curing, the best fit was also by the Fine Gaussian SVM with Gaussian kernel function, now with 0.56 kernel scale. It had RMSE=0.63 and $R^2=0.71$. The plots of model output vs. experimental result for VPS and MW curing are shown in Figures. 6 left panel, and right panel, respectively.

The prediction performance of support vector regression (SVR), considered a branch of the SVM method with wide use in regression problems, was particularly pronounced for data with smaller ultimate loads. The SVR model has been the most efficient model type for material property ranges, such as the ultimate tensile stress of the fiber-reinforced polymer, yield stress of the steel tube, and concrete compressive strength (Miao *et al.*,

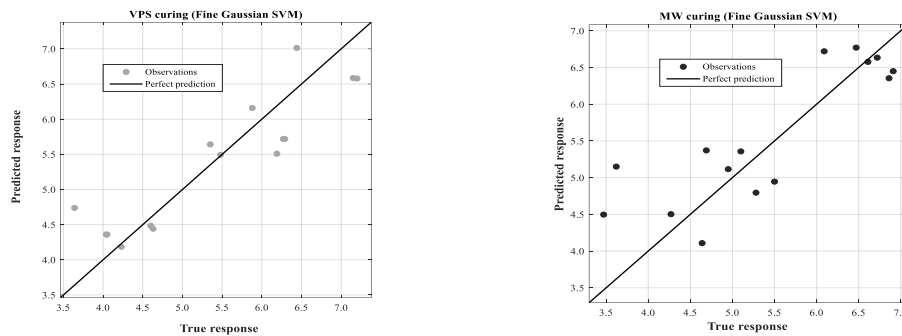


Figure 6. The plots of the model predicted response versus true response (the compressive strength) for the alternative curing methods. Left panel is for vinyl-plastic sheet (VPS) method, and right panel is for microwave energy (MW) method

2023). Therefore, the SVR model accurately predicted various material properties, including the compressive strength of concrete based on mix parameters. These predictions closely aligned with the experimental data, demonstrating a high correlation. The utilization of the SVR model allowed for the optimization of concrete formulations by identifying key parameters influencing compressive strength, leading to improved material performance.

Conclusions

Based on the study's findings on the influences of the amount of natural rubber latex on the properties of lightweight concrete mixed with aggregate, in both fresh and cured states, the following key conclusions and suggestions emerge:

1. The observed decrease in flowability with increased natural rubber latex content highlights a need for further research into optimizing concrete mixtures. Future investigations could explore innovative additives or alternative methodologies to counteract the flowability challenge and to minimize the resulting rise in the water-cement ratio.

2. The promising compatibility of quarry dust and natural rubber latex as additives for meeting industry standards opens avenues for future endeavors in construction materials. This study lays the groundwork for utilizing quarry dust, an industrial byproduct, and natural rubber latex, an agricultural product, to modify and improve lightweight concrete, thereby contributing to sustainable practices and resource utilization.

3. Classification of the studied samples according to industrial standards offers valuable benchmarks. Future research could delve into refining these classifications and exploring novel curing techniques to enhance concrete grades,

optimizing both structural integrity and energy efficiency.

Acknowledgement

The authors thank the Research and Development Office (RDO), Prince of Songkla University, Hat-Yai Campus, and Prince of Songkla University, Surat-Thani Campus, and we thank Mrs. Rinda Sanguanthai and Mrs. Sunisa Chuayjumnong who carried out the experiments.

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