Natural rubber latex as a polymer additive to modify the cement stabilized recycled concrete aggregate for pavement base applications

Caoutchouc naturel comme additif polymère pour modifier l'agrégat de béton recyclé stabilisé au ciment pour les applications de base de chaussée

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ABSTRACT: Cement stabilization is a low-cost treatment method that is useful for pavement base materials, especially recycled concrete aggregate (RCA). Cementitious binder has a direct effect on the strength and stiffness of the mixture. However, it might lead to the brittle behavior of cement stabilized mixture. In this study, natural rubber latex (NRL) was used as a polymer additive to modify the mechanical properties of cement stabilized RCA mixture. For this purpose, the cement contents of 3%, 5%, and 7% by mass of RCA were used, and the ratio of dry rubber content in NRL per cement content (r/c) of 5%, 10%, and 15% was added, respectively. The list of laboratory tests was conducted to obtain the basic physical properties of the materials, compaction characteristics of the mixes, as well as unconfined compressive strength and flexural strength of 7- and 28-day curing samples. Additionally, the experimental program also included scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) analyses. The test results clearly demonstrated that, at an optimum r/c ratio, cement-NRL stabilized RCA can enhance the compressive strength and flexural strength compared to cement-stabilized RCA. In addition, the UCS of all mixtures fully satisfied the minimum requirement specified by the Department of Highway (Thailand) for pavement base material. Based on the results of this study, NRL is recommended to improve the strength of cement stabilized RCA for pavement base applications.

RÉSUMÉ: La stabilisation au ciment est une méthode de traitement peu coûteuse qui est utile pour les matériaux de base des chaussées, en particulier les granulats de béton recyclés. Le liant cimentaire a un effet direct sur la résistance et la rigidité du mélange. Cependant, cela pourrait conduire au comportement fragile du mélange stabilisé au ciment. Dans cette étude, le caoutchouc naturel a été utilisé comme additif pour modifier les propriétés mécaniques du béton recyclé stabilisé au ciment. A cet effet, des teneurs en ciment de 3%, 5% et 7% ont été utilisées, et le rapport teneur en caoutchouc sec par teneur en ciment (r/c) de 5%, 10% et 15 % a été ajouté, respectivement. Des essais en laboratoire ont été effectuée pour obtenir les propriétés physiques de base des matériaux, les caractéristiques de compactage des mélanges, ainsi que la résistance à la compression et à la flexion non confinée des échantillons a 7 et 28 jours. En outre, le programme expérimental comprenait également des analyses par microscopie électronique à balayage et par spectroscopie à rayons X à dispersion d'énergie. Les résultats de ces essais ont clairement démontré qu'à un rapport r/c optimal, le béton recycle stabilisé au ciment- caoutchouc peut améliorer la résistance à la compression et la résistance à la flexion par rapport au béton recycle stabilisé au ciment. De plus, la résistance à la compression de tous les mélanges satisfaisait pleinement à l'exigence minimale spécifiée par le Département of Autoroutes (Thaïlande) pour le matériau de base de la chaussée. Sur la base des résultats de cette étude, la résistance à la compression est recommandée pour améliorer la résistance du béton recycle stabilisé au ciment pour les applications de base de chaussée.

KEYWORDS: natural rubber latex, recycled concrete aggregate, compressive strength, flexural strength, pavement applications.

1 INTRODUCTION

Over the last decade, many kinds of recycled materials or by-products have been employed for the pavement construction industry due to cost reduction and environmental benefits. In addition, the lack and exhaustion of the virgin aggregates and the enormous material quantities for road construction are also the main reasons for using the by-products (Huang et al., 2007). Recycled materials are often used in pavement applications such as RCA, reclaimed asphalt pavement (RAP), crushed bricks (CB), waste rock, and waste glass (Arulrajah et al., 2020). RCA is typically derived from demolished structures (e.g., foundations, bridge deck, columns) or tested concrete. Many studies suggested that RCA is the most suitable for substituting natural aggregates in the base/subbase layers as stabilized/unstabilized material (Yaowarat et al., 2018). The previous studies indicated that cement stabilized RCA has high compressive strength (e.g., 3% cement stabilized RCA sample has a compressive strength of 4.48 MPa after 28 curing days (Arulrajah et al., 2020)) as a result of the high strength bond between cement and RCA particles. However, there are some problems encountered with the cement stabilized RCA, which include small failure strain; the brittle behavior of cement stabilized RCA, which leads to low tensile strength or flexural strength, especially at high cement contents treated. In addition, flexural strength is one of the critical geotechnical parameters to predict the cracking behavior of pavement (Kunther et al., 2017).

For reducing these shortages, many proposed materials were employed for improving the tensile capacity of cement stabilized RCA, such as waste oil and asphalt emulsion (Zhou et al., 2019), steel fiber (Shahid & Thom, 1998), polyester fiber (Liu, 2015), polypropylene fiber (Grilli et al., 2013), rice husk ash (Bheel et al., 2018), polyvinyl alcohol and fly ash (Yaowarat et al., 2019).

Recently, some researchers have tried to improve the durability of concrete by adding natural rubber latex as a polymer admixture to the conventional concrete and recycled crushed concrete (Ismail et al., 2009), (Aswathi et al., 2017), (Muhammad & Ismail, 2012), (Vo & Plank, 2018). Despite that, there has been no research performed on using NRL to enhance the performance characteristics of cement-treated RCA for pavement base layer, which is the target of this study.

Thailand is known as the world's top natural rubber producer and exporter. Annually, nearly 1.1 million tons of construction waste is generated in Thailand. To mitigate construction costs and protect the natural resources, the Government of Thailand has signed an agreement to promote the utilization of NRL in roadway construction sectors (OTP Thailand, 2020).

2 MATERIALS AND METHOD

The material used in this research were recycled concrete aggregate, ordinary Portland cement (OPC), and natural rubber latex (Figure 1). In this study, RCA was obtained from wasted concrete beam after crushed by crusher machine with the nominal maximum size of 20 mm. Table 1 indicates the chemical components of the OPC. The NRL is supplied by Srijanoen rubber company. NRL contains surfactant sodium dodecyl sulfate (SDS) as a protein remover and colloidal stability of the latex; the main components of NRL are summarized in Table 2.

Figure 1. Physical appearance of RCA, NRL, and OPC.

In this study, RCA was mixed with the different cement content of 3%, 5%, and 7% (by mass of cement per RCA or c/RCA) and dry rubber content in NRL of 5%, 10%, and 15% (by mass of dry rubber per cement or r/c) to investigate the influence of rubber latex on the compressive and stiffness of cement stabilized RCA material as a polymer admixture to the blend. The studied mixtures are designed, namely, as seen in Table 3.

The list of laboratory tests was performed to determine the geotechnical properties of RCA, including particle size distribution, water absorption, particle density, flakiness index, organic content, Los Angeles (LA) abrasion loss, pH value, California bearing ratio (CBR), modified Proctor compaction. The compressive strength of RCA blends was measured by unconfined compressive strength (UCS) test, and three-point bending tests were conducted to assess the stiffness of RCA blends at 7 and 28 curing days. Scanning Electron Microscope (SEM) was performed to examine the morphography of cement hydration products between RCA particles and the interactions among rubber film network-cement hydration products-RCA particles. Energy Dispersive X-ray Spectroscopy (EDS) has measured the quantity of carbon, calcium, and silicate elements in the various cement-NRL stabilized RCA blends.

Table 1. Chemical compositions of OPC.

Composition	Content (%)
SiO_2	20.1
CaO	65.0
Al_2O_3	4.7
Fe_2O_3	3.2
MgO	2.6
SO_3	3.3
Loss of ignition	0.9

Table 2. Properties of NRL.

Properties	Value
Total solid contents (% by weight)	33.06
Dry rubber contents (% by weight)	30.79
Sludge content (% by weight)	2.46
Coagulum content (% by weight)	0.024
Specific gravity (Gs)	0.96
pH	8

Table 3. The mix design proportions.

Proportions	Mixture name
100% RCA	100RCA
100% RCA, 3% Cement	3C-RCA
100% RCA, 3% Cement, 5% r/c	3C5R-RCA
100% RCA, 3% Cement, 10% r/c	3C10R-RCA
100% RCA, 3% Cement, 15% r/c	3C15R-RCA
100% RCA, 5% Cement	5C-RCA
100% RCA, 5% Cement, 5% r/c	5C5R-RCA
100% RCA, 5% Cement, 10% r/c	5C10R-RCA
100% RCA, 5% Cement, 15% r/c	5C15R-RCA
100% RCA, 7% Cement	7C-RCA
100% RCA, 7% Cement, 5% r/c	7C5R-RCA
100% RCA, 7% Cement, 10% r/c	7C10R-RCA
100% RCA, 7% Cement, 15% r/c	7C15R-RCA

A two-stage mixing approach (TSMA) (Tam et al., 2005) has been applied during the mixing process to produce the uniform mixture and improve the quality of specimens created. Figure 2 displays the processing of sample preparation in this study by TSMA.

Figure 2. TSMA for cement-NRL stabilized RCA sample.

3 RESULTS AND DISCUSSION

3.1 *Geotechnical properties of RCA material*

Results from the sieve analysis are displayed under the particle size distribution curve in Figure 3. This curve was compatible with the upper and lower grading limits for pavement base material as described in the Department of Highways' Standard, Thailand (DH-S201/2556) (DOH Thailand, 2013) and ASTM standard (ASTM D1241-15, 2015). The grading plot has demonstrated that the RCA in this study is appropriate for use in the pavement base layer.

Table 4 summarizes the particle size distribution parameters, including grading characteristics (D_{10}, D_{30}, and D_{60}), coefficient of uniformity (C_u), coefficient of curvature (C_c), coarse and fine fraction contents. According to the Unified Soil Classification System (USCS) (ASTM D2487-17, 2017), RCA material used in this study has been categorized as well-graded gravel (GW).

As stated in Table 4, the specific gravity of coarse RCA (retained on 4.75 mm sieve) is slightly higher than the fine portion (passed through 4.75 mm sieve). The water absorption of coarse aggregates is lower than those of fine aggregates, which have a larger specific surface; therefore, they absorb more water than the coarse ones (Poon & Chan, 2006).

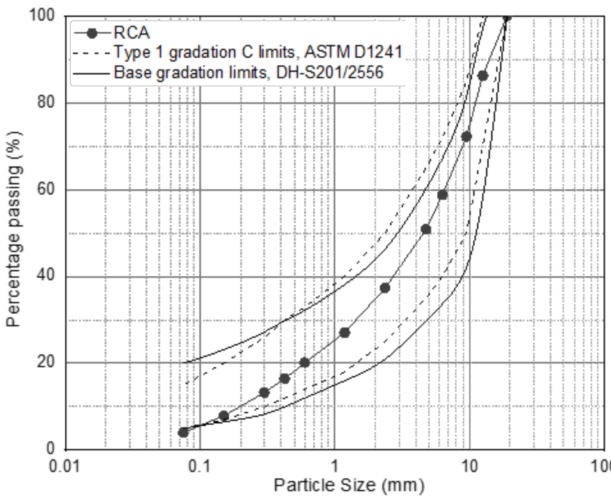

Figure 3. Particle size distribution curve of RCA material.

In the present study, the organic content of RCA is at a low rate, typically similar to some previous studies by Arulrajah et al. 2013 and Mohammadinia et al., 2015. The flakiness index is smaller than the limit of 35 for pavement base materials. The LA abrasion loss value is 38.1; for implementation of pavement base layer, this result is presented below the approved range (< 40) as referenced on VicRoads RC 500.02 (Vicroads, 2017). The organic content was found to be low-value whilst the pH value is over 7, which indicates that RCA material is an alkaline environment by nature.

Table 4. Geotechnical properties of RCA.

Properties	Testing standards	Values
Organic content (%)	ASTM D2974	2.56
Fine content (%)	ASTM D422	4.0
Sand content (%)	ASTM D422	46.8
Gravel content (%)	ASTM D422	49.2
D10	ASTM D2487	0.2
D30	ASTM D2487	1.5
D60	ASTM D2487	6.8
Coefficient of curvature (C_c)	ASTM D2487	1.65
Coefficient of uniformity (C_u)	ASTM D2487	34.0
Soil classification	ASTM D2487	GW
Specific gravity - coarse	ASTM C127	2.30
Specific gravity - fine	ASTM C128	2.17
Water absorption - coarse (%)	ASTM C127	6.32
Water absorption - fine (%)	ASTM C128	7.95
Flakiness index	BS 812:105.1	15.6
LA abrasion loss	ASTM C1311	38.1
pH	ASTM D4972	12.2
MDD (kN/m^3)	ASTM D1557	1.89
OLC (%)	ASTM D1557	11.7
CBR	ASTM D1883	195

3.2 *Modified compaction characteristics*

The compaction test results are expressed in Figure 4. The MDD values for the cement stabilized RCA sample was observed to increase with increasing cement content. In comparison between unstabilized- and stabilized samples, the MDD values of cement stabilized RCA samples were increased by 1.9%, 2.0%, and 2.2%, corresponding to the content of cement of 3%, 5%, and 7%. This growth is due to the influence of cement particles to the friction resistance between RCA particles, which led to the denser structure after compaction. However, the MDD of cement-NRL stabilized RCA blends was decreased by the increase in r/c ratio. The reduction of MDD by the addition of r/c ratio may be due to the rubber latex acting as a barrier that impedes lubrication of the particle surface that reduces the compactability of the mixtures.

The optimum liquid content (OLC) from compaction test of cement stabilized RCA blends also slightly increased when cement content was increased; in consequence of the amount of non-homogeneous concrete and mortar present in RCA particles, the variation of OLC value of cement stabilized RCA was insignificant (Mohammadinia et al., 2015). The OLC values of cement-NRL stabilized RCA decreased with increasing of the r/c ratio; this reduction might have resulted from the hydrophobic behavior of rubber in which hydrophobic molecules and surfaces of rubber repel water (Jose & Kasthurba, 2021).

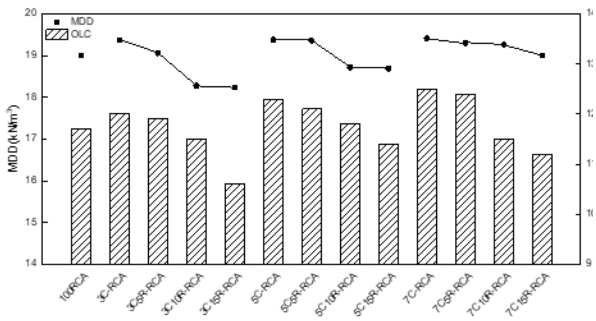

Figure 4. Modified Proctor compaction test results.

3.3 *Unconfined compressive strength*

Figure 5 compares the compressive strength of RCA blends after 7 and 28 days of curing. According to the Department of Highways (DOH), Thailand, the UCS strength after 7 days of curing for cement stabilized base material shall not be less than 1.724 MPa (DOH Thailand, 1996). The results of this study expressed that cement- and cement-NRL stabilized RCA samples satisfied the minimum requirement.

The UCS value generally increased linearly with the increase in cement content and curing time. Figure 5 demonstrated that NRL additive could increase the UCS strength of cement stabilized RCA. The highest compressive strength is found at optimum r/c ratio of 3C10R-, 5C5R-, and 7C5R-RCA samples and 7-day UCS values were improved up to 3.8%, 12.6%, and 8.7%, respectively.

Therefore, it can be concluded that the optimum r/c ratio is more helpful for the development of the compressive strength of the blends. Nevertheless, exceeding the optimum r/c value increases the extent the polymer film tends to prohibit the development of the cement hydration process (*Section 3.5*).

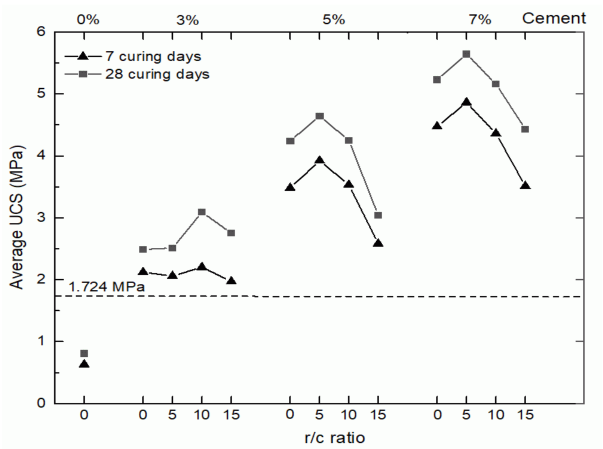

Figure 5. UCS values of RCA blends at 7 and 28 curing days.

3.4 *Flexural strength*

The flexural strength is expressed as modulus of rupture, a measure of peak load that stabilized materials can withstand under the moment without shear force (Arulrajah et al., 2020). Figure 6 shows the flexural strength of RCA blends at different cement and r/c ratio at the ages of 7 and 28 curing days.

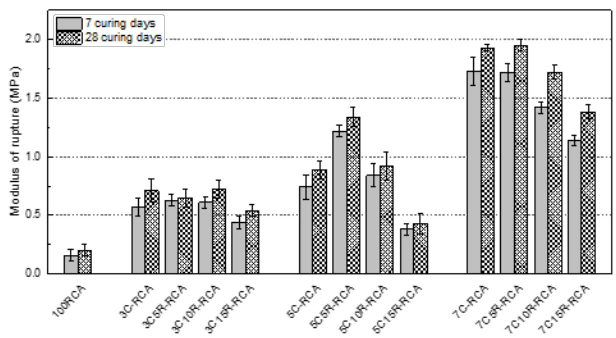

Figure 6. Flexural strength of RCA blends.

A similar observation was made in the UCS test; the amount of NRL additive in the stiffness development at an optimum r/c ratio was determined as 10%, 5%, and 5% for 3%, 5%, and 7% cement, respectively. However, the input of rubber latex content in excess of the optimum r/c ratio will cause the flexural strength of blends to deteriorate, particularly for the cement-NRL stabilized RCA with r/c ratio equal to 15% (3C15R-, 5C15R-, 7C15R-RCA). It can be seen that the growth in stiffness is due to the strong bond between the RCA aggregates based on cement binder and forms in conjunction with the coating function of rubber films or bridges.

The relationship between UCS and flexural strength was plotted in Figure 7, and an approximate value of the flexural strength can be obtained from UCS (ACI, 2009) by a polynomial function as stated in Equation (1).

$$FS = 0.0606(UCS)^2 - 0.0169(UCS) + 0.2212 \; (R^2 = 0.89) \quad (1)$$

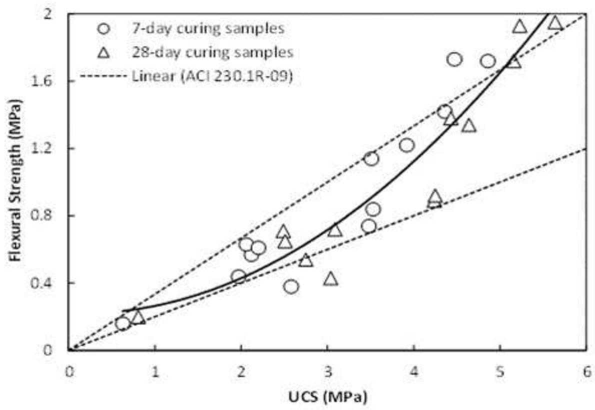

Figure 7. Relationship between UCS and flexural strength.

3.5 *Morphological and microstructural analysis*

The morphological investigation by SEM of 5C-, 5C5R-, and 5C15R-RCA samples after 28 curing days were conducted and displayed in Figure 8. The strength development of cement stabilization depends on the presence of calcium silicate hydrate (C-S-H), ettringite formation in mortar and specimen during the curing time. It was observed from SEM images that the amount of cement hydration products are the greatest at optimum r/c ratio (5C5R-RCA), whereas when r/c ratio that is excessively higher or lower than the optimum will be reduced in the growth of cement hydration products. As a consequence, the strength of cement-NRL stabilized RCA samples decreased when r/c ratio excessed the optimum value.

The EDS analysis of cement- and cement-NRL stabilized RCA with 5% cement content and r/c ratio of 5%, 15% are displayed in Figure 9. The Ca and Si are the main elements, which are responsible for the strength of the sample, while C is presented in the amount of rubber latex in the mixture (Sukmak et al., 2020). Due to the influence of the NRL additive, the peak of Ca and Si decreases as r/c increases; a clear trend is observed for the sample with the highest r/c ratio. The improvement of both compressive strength and flexural strength at optimum r/c ratio was indicated that might be contributed to the adhesive bonding strength of rubber films between the cementitious matrix and recycled aggregates.

4 CONCLUSIONS

The study was conducted to research the influence of NRL on the physical and mechanical properties of cement-NRL stabilized RCA as a polymer additive. As a follow-up to this research, the results show that NRL can improve the compressive and flexural strength at an optimum r/c ratio.

The UCS and flexural strength values indicated that r/c of 10%, 5%, and 5% were found to be the optimum ratio for 3%, 5%, and 7% cement-NRL stabilization RCA, respectively. Accelerated hydration process due to the effect of NRL and better bond coat was achieved at optimum r/c ratio which contributed to the strength development of cement-NRL stabilized RCA blends. However, exceeding the optimum r/c value leads to lower Ca and Si, which results in a reduction of the strength of blends.

In conclusion, this study revealed the possibility of using NRL in developing the strength and stiffness of cement stabilized RCA as a road base construction material.

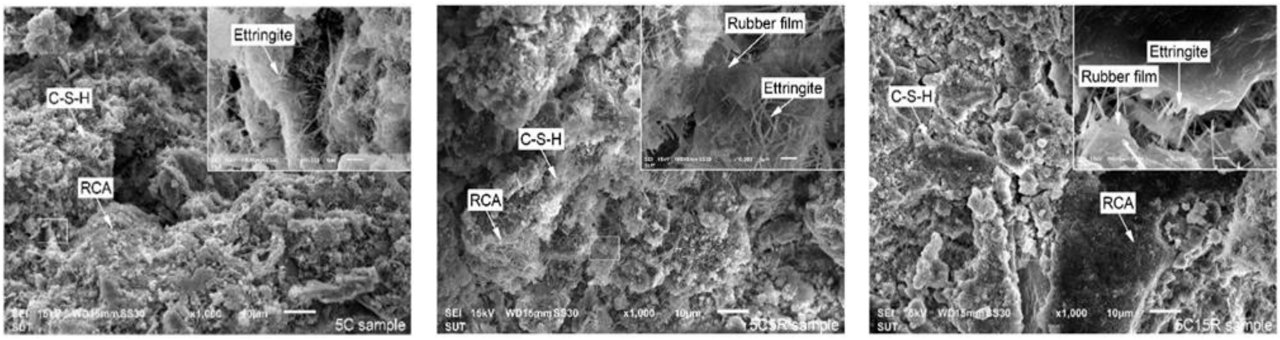

Figure 8. SEM photographs of 5C-, 5C5R-, and 5C15R-RCA samples.

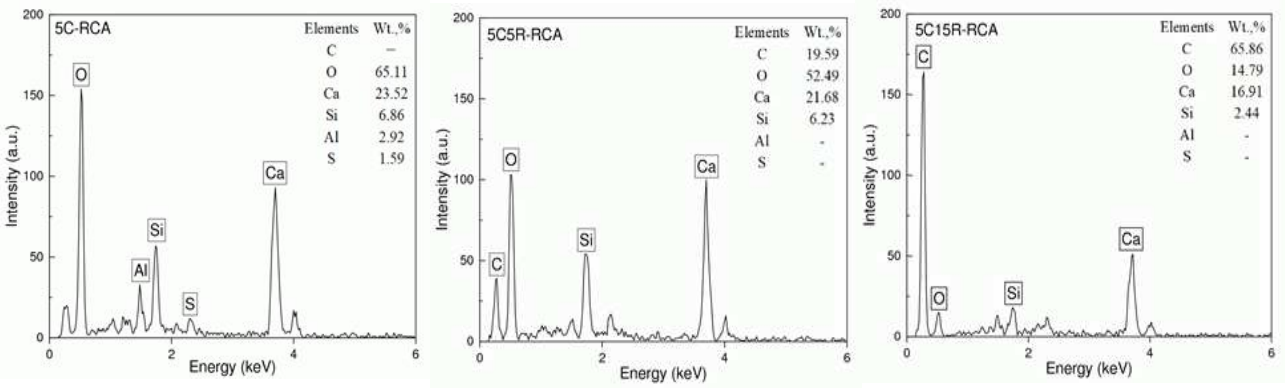

Figure 9. EDS analysis of RCA blends.

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6 REFERENCES

ACI. (2009). American Concrete Institute - Report on soil cement. *Byulleten Eksperimentalnoi Biologii i Meditsiny*, *76*(7), 17.

Arulrajah, A., Piratheepan, J., Disfani, M. M., & Bo, M. W. (2013). Geotechnical and geoenvironmental properties of recycled construction and demolition materials in pavement subbase applications. *Journal of Materials in Civil Engineering*, *25*(8), 1077-1088. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000 652.

Arulrajah, A., Perera, S., Wong, Y. C., Horpibulsuk, S., & Maghool, F. (2020). Stiffness and flexural strength evaluation of cement stabilized PET blends with demolition wastes. *Construction and Building Materials*, *239*, Article 117819. https://doi.org/10.1016/j.conbuildmat.2019.117819.

ASTM D1241-15. (2015). Standard Specification for Materials for Soil-Aggregate Subbase, Base, and Surface Courses. https://doi.org/10.1520/D1241-15.

ASTM D2487-17. (2017). Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). https://doi.org/10.1520/D2487-17E01.

Aswathi, K. P., Hanna, P., George, J. K., & Shameer, K. (2017). Effect of natural rubber latex as admixtures in concrete. *International Research Journal of Engineering and Technology(IRJET)*, *4*(4), 2031-2034.

Bheel, N., Meghwar, S. L., Sohu, S., Khoso, A. R., Kumar, A., & Shaikh, Z. H. (2018). Experimental study on recycled concrete aggregates with rice husk ash as partial cement replacement. *Civil Engineering Journal*, *4*(10), 2305. https://doi.org/10.28991/cej-03091160.

DOH Thailand. (1996). Thailand Department of Highways, DH S204/2532 - Standard for highway construction (soil-cement base). *Thailand*.

DOH Thailand. (2013). Thailand Department of Highways, DH S201/2556 - Standard for highway construction. *Thailand*.

Grilli, A., Bocci, M., & Tarantino, A. M. (2013). Experimental investigation on fiber-reinforced cement-treated materials using reclaimed asphalt. *Construction and Building Materials*, *38*, 491–496. https://doi.org/10.1016/j.conbuildmat.2012.08.040.

Huang, Y., Bird, R. N., & Heidrich, O. (2007). A review of the use of recycled solid waste materials in asphalt pavements. *Resources, Conservation and Recycling*, *52*(1), 58-73. https://doi.org/10.1016/j.resconrec.2007.02.002.

Ismail, M., Muhammad, B., & Mohamad, A. (2009). Durability performance of natural rubber latex modified concrete. *Malaysian Journal of Civil Engineering*, *21*(2), 195-203. https://doi.org/10.11113/mjce.v21n2.232.

Jose, A., & Kasthurba, A. K. (2021). Laterite soil-cement blocks modified using natural rubber latex: Assessment of its properties and performance. *Construction and Building Materials*, *273*, 121991. https://doi.org/10.1016/j.conbuildmat.2020.121991.

Kunther, W., Ferreiro, S., & Skibsted, J. (2017). Influence of the Ca/Si ratio on the compressive strength of cementitious calcium-silicate-hydrate binders. *Journal of Materials Chemistry A*, *5*(33), 17401-17412. https://doi.org/10.1039/c7ta06104h.

Liu, Z. (2015). Experimental research on the engineering characteristics of polyester fiber-reinforced cement-stabilized macadam. *Journal of Materials in Civil Engineering*, *27*(10), 04015004. https://doi.org/10.1061/(asce)mt.1943-5533.0001251

Mohammadinia, A., Arulrajah, A., Sanjayan, J., Disfani, M. M., Bo, M. W., & Darmawan, S. (2015). Laboratory evaluation of the use of cement-treated construction and demolition materials in pavement base and subbase applications. *Journal of Materials in Civil Engineering*, *27*(6). https://doi.org/10.1061/(ASCE)MT. 1943-5533.0001148.

Muhammad, B., & Ismail, M. (2012). Performance of natural rubber latex modified concrete in acidic and sulfated environments. *Construction and Building Materials*, *31*, 129-134. https://doi.org/10.1016/j.conbuildmat.2011.12.099.

OTP Thailand. (2020). Thailand Office of Transport and Traffic Policy and Planning - Annual report. *Thailand*.

Poon, C. S., & Chan, D. (2006). Feasible use of recycled concrete aggregates and crushed clay brick as unbound road sub-base. *Construction and Building Materials*, *20*(8), 578-585. https://doi.org/10.1016/j.conbuildmat.2005.01.045.

Shahid, M. A., & Thom, N. H. (1998). Steel fiber reinforcement in cement-bound bases. *Proceedings of the Institution of Civil Engineers: Transport*, *129*(1), 34-43. https://doi.org/10.1680/

itran.1998.30091.
Sukmak, G., Sukmak, P., Horpibulsuk, S., Yaowarat, T., Kunchariyakun, K., Patarapaiboolchai, O., & Arulrajah, A. (2020). Physical and mechanical properties of natural rubber modified cement paste. *Construction and Building Materials*, *244*, Article 118319. https://doi.org/10.1016/j.conbuildmat.2020.118319.
Tam, V. W. Y., Gao, X. F., & Tam, C. M. (2005). Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach. *Cement and Concrete Research*, *35*(6), 1195-1203. https://doi.org/10.1016/j.cemconres.2004.10.025.
Vicroads. (2017). Registration of crushed rock mixes. *Vicroads Code of Practice RC 500.02*, 1-9.
Vo, M. L., & Plank, J. (2018). Evaluation of natural rubber latex as film forming additive in cementitious mortar. *Construction and Building Materials*, *169*, 93-99. https://doi.org/10.1016/j.conbuildmat.2017.12.098.
Yaowarat, T., Horpibulsuk, S., Arulrajah, A., Mirzababaei, M., & A Rashid, A. S. (2018). Compressive and flexural strength of polyvinyl alcohol-modified pavement concrete using recycled concrete aggregates. *Journal of Materials in Civil Engineering*, *30*(4), Article 04018046. https://doi.org/10.1061/(asce)mt.1943-5533.0002233.
Yaowarat, T., Horpibulsuk, S., Arulrajah, A., Mohammadinia, A., & Chinkulkijniwat, A. (2019). Recycled concrete aggregate modified with polyvinyl alcohol and fly ash for concrete pavement applications. *Journal of Materials in Civil Engineering*, *31*(7), 04019103. https://doi.org/10.1061/(asce)mt. 1943-5533.0002751.
Zhou, J., Zeng, M., Chen, Y., & Zhong, M. (2019). Evaluation of cement stabilized recycled concrete aggregates treated with waste oil and asphalt emulsion. *Construction and Building Materials*, *199*, 143–153. https://doi.org/10.1016/j.conbuildmat.2018.12.028.