ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

Effects of Crumb Rubber on Properties of High-Calcium Fly Ash Geopolymer Mortars

Pisit Thongjub[1], Peem Nuakong[1], Pitcha Jongvivatsakul[2], Nareenart Raksuntorn[3], Boonsap Witchayangkoon[1*], Winai Raksuntorn[1], Sayan Sirimontree[1]

[1] *Department of Civil Engineering, Thammasat School of Engineering, Thammasat University, THAILAND.*

[2] *Center of Excellence in Innovative Construction Materials, Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, THAILAND.*

[3] *Faculty of Industrial Technology, Suan Sunandha Rajabhat University, THAILAND.*

**Corresponding Author (Tel: +66-25643005, Email: wboon @engr.tu.ac.th).*

Paper ID: 13A2A

Volume 13 Issue 2

Received 23 September 2021

Received in revised form 19 December 2021

Accepted 26 December 2021

Available online 05 January 2022

Keywords:

Waste tires; Cement mortar; Mortar compressive strength; Alkali-activated materials; Paving block.

Abstract

In this study, the influence of crumb rubber on the properties of geopolymer mortar was investigated. The crumb rubber was used as fine aggregate to reduce consumption of natural river sand. The rubber replacement levels namely 10%, 20%, and 30% by volume of the sand was chosen. The results were compared with the control specimen made with only river sand. It was found that the compressive strength of mortars was decreased with increasing the crumb rubber content. An increase in water absorption was observed. However, the strength of the paving block specimen made with 10% rubber meets the requirements for application in interlocking paving blocks. Its compressive strength at the age of 7 days was 85.0 MPa.

Disciplinary: Civil Engineering & Material Technology (Cement, Geopolymer, Construction Materials, Pavement).

Cite This Article:

Thongjub, P., et al. (2022). Effects of Crumb Rubber on Properties of High-Calcium Fly Ash Geopolymer Mortars. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 13*(2), 13A2A, 1-10. http://TUENGR.COM/V13/13A2A.pdf DOI: 10.14456/ITJEMAST.2022.22

1 Introduction

Geopolymer is an alternative class of cementitious materials. It can be produced by mixing aluminosilicate materials, such as metakaolin and fly ash, with alkaline solutions. While the geopolymer can be formed into a variety of shapes and sizes in the fresh state, it can withstand the applied load after hardening similar to Portland cement-based materials. Compared to Portland cement, the geopolymer possesses many unique properties, such as low creep, low shrinkage, and is superior to acid attack. In addition, geopolymers show high strength at early ages after heat curing (Diaz-Loya et al., 2011; Park et al., 2016).

Waste rubber tires arising from the rapid revolution in cars and the transportation industry are a relevant concern in the pollution of the environment (Sharaky et al., 2020). The waste is a long-lasting material and non-biodegradable. The waste rubber ties are required appropriate management since landfilling and fuel combustion create serious environmental problems due to the leaching of toxic and harmful elements (Bala and Gupta, 2021). Recycling waste tires is one of the most effective ways to reduce the huge amounts of this waste.

The objective of this study was to evaluate the performance of geopolymer mortar made from a waste tire. The crumb rubber was used to replace 10%, 20% and 30% of the natural river sand by volume. The workability, unit weight, compressive strength, and water absorption of geopolymer mortars were investigated. The results were compared with the specimen containing 100% natural river sand. In addition, interlocking paving block specimens were cast to evaluate the feasibility of the paving block made with the waste tire.

2 Literature Review

2.1 Geopolymer

Geopolymer is produced by a reaction of solid aluminosilicate materials and alkaline activators. Fly ash is one of the most commonly used for making geopolymers since it is the most readily available aluminosilicate material; in addition, it is rich in silica and alumina required for geopolymerization processes. Compositions of alkaline activators also have a significant influence on the properties of geopolymers. The sodium hydroxide concentration of 10 M was recommended for the leaching of silica and alumina from fly ash particles (Hwang and Huynh, 2015). Previous studies indicated that the optimum sodium silicate-to-sodium hydroxide ratio of 1 gave the best performance in terms of strength (Adam and Horianto, 2014; Nuaklong et al., 2021a). The rate of strength gain can be accelerated by using heat curing, usually in the range of 60-100 °C (Jindal, 2019; Kong and Sanjayan, 2010).

2.2 Utilization of Waste Tire in Cementitious Materials

Many studies are available in the literature related to cementitious materials made with the waste tire. In general, the crumb rubber was used as a sand replacement to reduce the depletion of natural resources. Benazzouk et al. (2003) studied the properties of Portland cement composites made by using crumb rubber as aggregates. They found that the compressive strength was decreased, especially when the sand was replaced with the rubber at 50% by volume. However, a slight reduction in compressive strength was observed for the replacement level of 10% (Abdelmonem et al., 2019). Mohsin and Fahad (2015) found that cement composites containing crumb rubber have excellent insulation properties. Also, long hollow blocks and bricks can be made by using crumb rubber (Sodupe-Ortega et al., 2016). Despite extensive research on the use of waste tires for making either mortar or concrete, the properties of geopolymer mortars made from waste tires have been reported by a few authors.

3 Method

3.1 Materials

High calcium fly ash with a specific gravity of 2.4 was used for preparing geopolymer mortar. Alkaline activators used in the investigation were 10 M of sodium hydroxide and sodium silicate solutions. The sodium silicate was a commercially available solution with chemical compositions of 34.0% SiO_2, 15.8% Na_2O, and 50.2% H_2O. Fine aggregates used for making the mortar were river sand and crumb rubber tires (see Figure 1). While the specific gravity and fineness modulus of the river sand were 2.61 and 3.03, the corresponding values for the waste tire were 0.65 and 2.73, respectively. Their gradations were determined according to ASTM C136 (ASTM, 2019). The results are shown in Figure 2.

Figure 1: Aggregates used in the investigation: (a) river sand; and (b) crumb rubber ties

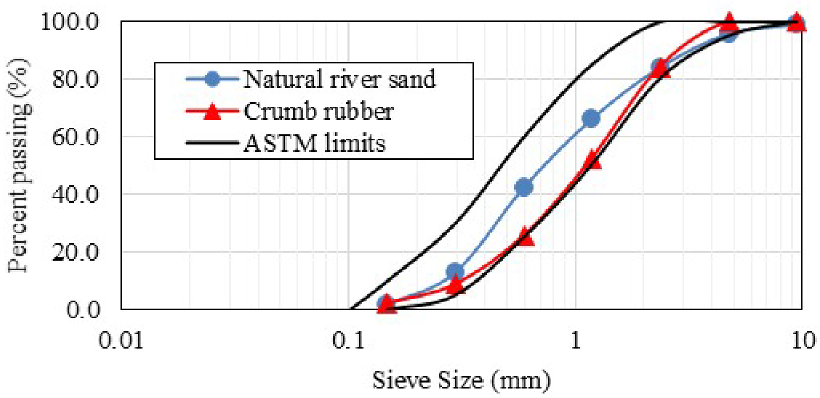

Figure 2: Gradation of aggregates

3.2 Mixing and Casting

Table 1 shows mortar mix proportions. The sand-to-fly ash ratio used for the control mixture (CON) was kept constant at 2.75 by weight. The letter "R" indicates that the crumb rubber was added to geopolymer mortar. The final label numbers represent the content of the rubber (% by volume) in the mixtures. First, the fly ash was added to the sodium hydroxide solution and mixed for 3 min. Second, river sand and the waste tire were mixed for 3 min. The sodium silicate was added and mixed for 3 min in the last step.

Table 1: Mix proportions of geopolymer mortars (g).

Mixes	Fly ash	Sodium hydroxide	Sodium silicate	River sand	Crumb rubber
CON	100	30	30	275	-
R-10	100	30	30	247.5	6.75
R-20	100	30	30	220	13.5
R-30	100	30	30	192.4	20.2

After mixing, the fresh mortar was poured into molds. The specimens were left at room temperature for 1 h and then wrapped with plastic sheets. After that, the mortar specimens were put in an oven for heat curing. Based on previous research (Nuaklong et al., 2021b), the curing temperature and curing time used in this investigation were 80 °C and 24 h, respectively. Hardened properties of geopolymer mortars were tested at the age of 7 days.

3.3 Experimental Details

Slump flow of geopolymer mortars was done in accordance with ASTM C1611 (ASTM, 2018). Three 50×50×50 mm^3 cube specimens were cast to determine their strength. Also, the three 100×100×100 mm^3 cubes were prepared for evaluating the water absorption of mortars. While the compressive strength was determined according to ASTM C109 (ASTM, 2016), the water absorption was done by using ASTM C642 (ASTM, 2013). In addition, the paving block specimens were cast to determine the compressive strength. Dimensions of the paving blocks are shown in Figure 3.

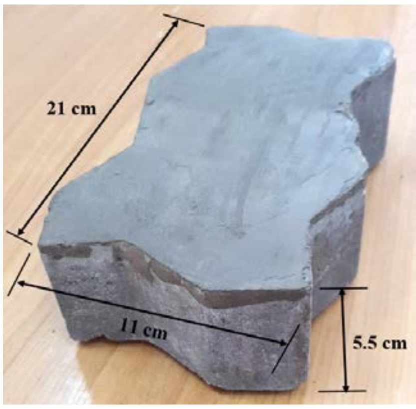

Figure 3: Interlocking paving block used in the investigation

4 Result and Discussion

4.1 Slump Flow

Slump flow values of geopolymer mortars are shown in Figure 4. The values were 68.3, 64.8, 62.8, and 61.4 cm for CON, R-10, R-20 and R-30 mixtures, respectively. It can be seen that the slump flow was decreased when the crumb rubber was added. The lowest value was obtained for the mixture made from 30% crumb rubber. The observed result is consistent with previous findings regarding the inclusion of the waste rubber in Portland cement-based cementitious materials (Alsaif et al., 2018; Moustafa and ElGawady, 2015). Pham et al. (2021) suggested that the reason for this is the rough surface of the crumb rubber.

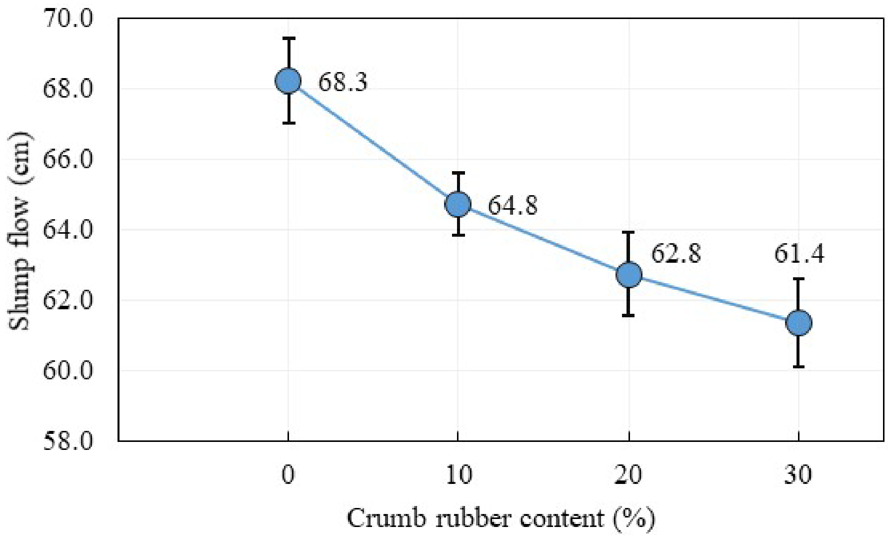

Figure 4: Slump flow values of geopolymer mortars

4.2 Unit Weight

Unit weight values of all 4 different mortar mixtures are presented in Figure 5. The values for CON, R-10, R-20 and R-30 were 2101, 2008, 1915 and 1793 kg/m^3, respectively. As compared with the CON specimen, the unit weight of mortar mixtures was reduced by around 4%-26% when the crumb rubber replacement ratio changed from 0% to 30%. This is in line with previous studies found in the literature (AbdelAleem et al., 2018; Aslani et al., 2018), which reported that incorporating crumb rubber reduced the unit weight of Portland cement concrete compared to the inclusion of 100% river sand. The main reason for this behavior lies in the fact that the density of the crumb rubber was much lower than that of the natural river sand.

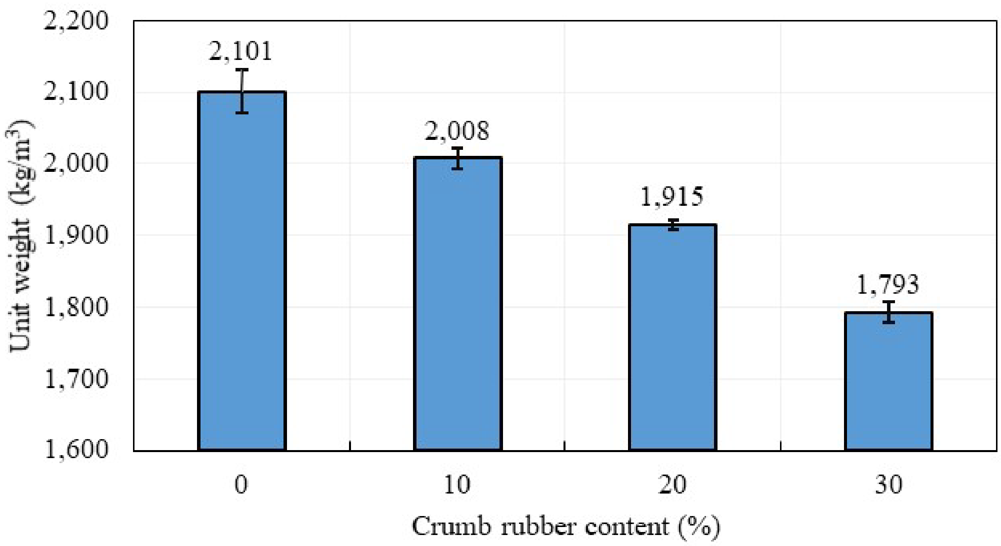

Figure 5: Unit weight values of geopolymer mortars

4.3 Compressive Strength

As shown in Figure 6, the compressive strength of geopolymer mortars varied in the range 13.7-58.7 MPa. It can be seen from Figure 6 that the compressive strength of geopolymer mortar at the age of 7 days decreased as the crumb rubber substitution rate increased. Among the three specimens made with crumb rubber, the R-30 specimen has the lowest compressive strength value of 13.7 MPa. This can be attributed to: (1) the difference in the strain capacity of crumb rubber and other ingredients was high (Ameri et al., 2020); (2) the weak adhesion between the paste and crumb rubber (Lv et al., 2015; Youssf et al., 2017); and (3) the entrapped air was increased when the crumb rubber was included in the mix (Pham et al., 2019).

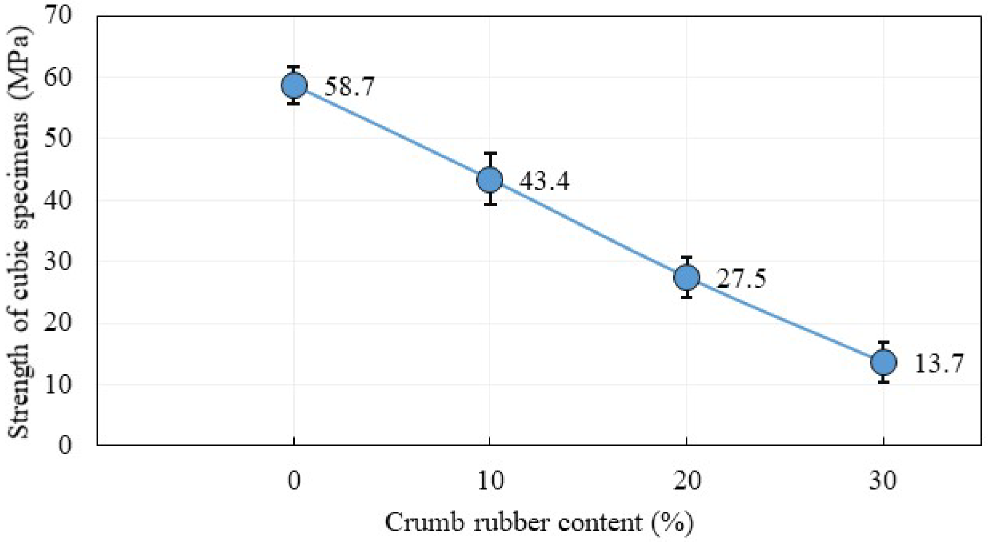

Figure 6: Compressive strength values of cubic geopolymer mortars

4.4 Water Absorption

The water absorption values of geopolymer mortars measured at the age of 7 days are demonstrated in Figure 7. The results showed that the geopolymer mortar with higher waste rubber replacement ratios showed higher water absorption capacity. For example, the water absorption of R-30 mixture was 9.2%, which was 2.3% higher than that of the control mixture (CON). Similar trend was also observed by Dong et al. (2021) and Muñoz-Sánchez et al. (2017). This was attributed to the agglomeration of crumb rubber aggregate, leading to the increased porosity and microcracks inside the specimen.

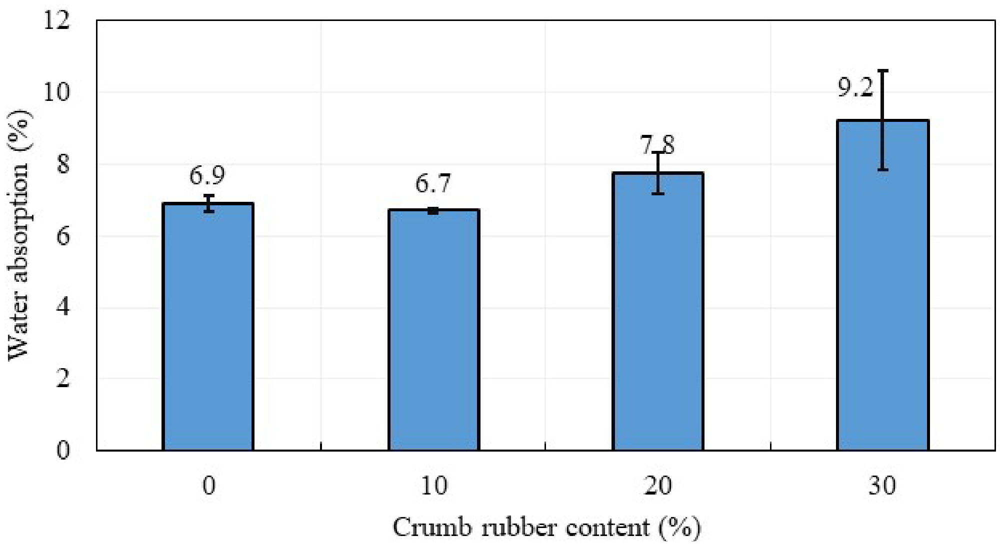

Figure 7: Water absorption capacity of geopolymer mortars

4.5 Strength of Interlocking Paving Blocks

Figure 8 presents the 7-day compressive strengths of the paving blocks. Like cubic specimens, the compressive strength of paving block specimens was reduced when the crumb rubber was added. The compressive strength of paving block specimens containing 10%, 20%, and 30% crumb rubber was 19%, 56%, and 68% lower than that of the specimen made with only river sand (CON). However, it has been confirmed from the results that the R-10 mixtures achieved the required compressive strength for paving blocks. Its compressive strength was higher than 55 MPa, which is required per ASTM C936 (ASTM, 2021) specification for interlocking paving units.

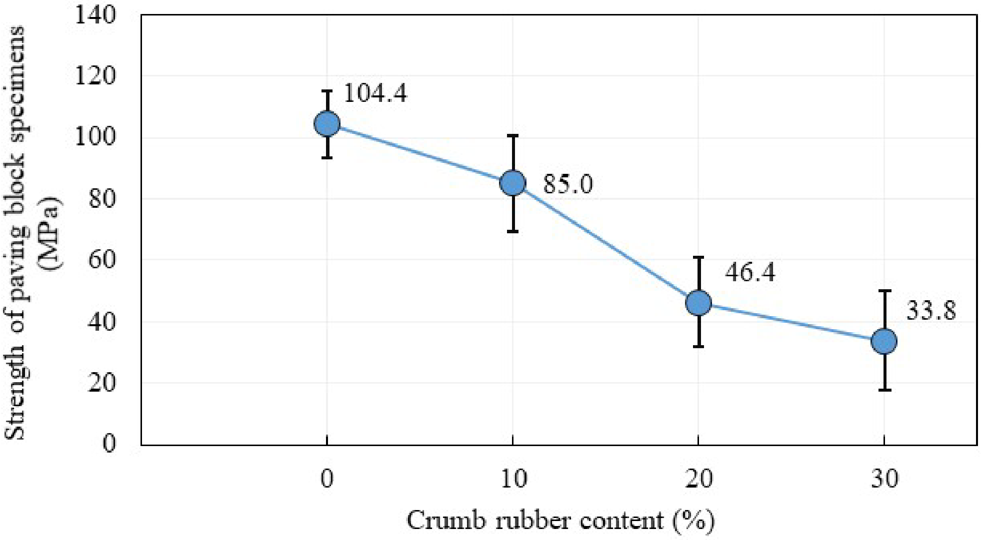

Figure 8: Compressive strength of interlocking paving blocks at the age of 7 days

It was noticed that the testing of compressive strength based on paving block specimen was found to give higher strength than the same mixture tested on the 5-cm standard cube. The reason for this is a reduction in the slenderness ratio. In other words, the available load-carrying area of the paving block specimen is much higher than that of the cubic specimen, while the height is very similar (see Figure 3). This indicates that the effect of change in geometry of specimen on the strength plays an important role in determining the compressive strength of cementitious materials.

5 Conclusion

In this study, the effect of crumb rubber on the properties of geopolymer mortar was investigated to encourage more application of the waste for construction material. The results showed that the workability of high calcium fly ash geopolymer mortars made with crumb rubber was lower than that of the mortar containing only river sand. The 7-day compressive strength of the mortar specimen was decreased when the crumb rubber was added. The maximum reduction in the strength occurred at 30% crumb rubber replacement for natural river sand. The water absorption of geopolymer mortar increased with increasing crumb rubber content. However, it should be noted that the paving block geopolymer mortar made with 10% crumb rubber can be used for interlocking paving blocks based on the ASTM specification. It showed the 7-day compressive strength of 85.0 MPa.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

7 Acknowledgment

The authors acknowledge the financial supports from the Research Unit of Thammasat University, and the Department of Civil Engineering, Thammasat School of Engineering, Thammasat University.

8 References

AbdelAleem, B. H., Ismail, M. K., & Hassan, A. A. (2018). The combined effect of crumb rubber and synthetic fibers on impact resistance of self-consolidating concrete. *Construction and Building Materials*, *162*, 816-829.

Abdelmonem, A., El-Feky, M. S., Nasr, E. S. A., & Kohail, M. (2019). Performance of high strength concrete containing recycled rubber. *Construction and Building Materials*, *227*, 116660.

Adam, A. A., & Horianto, X. X. X. (2014). The effect of temperature and duration of curing on the strength of fly ash based geopolymer mortar. *Procedia engineering*, *95*, 410-414.

Alsaif, A., Bernal, S. A., Guadagnini, M., & Pilakoutas, K. (2018). Durability of steel fibre reinforced rubberised concrete exposed to chlorides. *Construction and Building Materials*, *188*, 130-142.

Ameri, F., Shoaei, P., Musaeei, H. R., Zareei, S. A., & Cheah, C. B. (2020). Partial replacement of copper slag with treated crumb rubber aggregates in alkali-activated slag mortar. *Construction and Building Materials*, *256*, 119468.

Aslani, F., Ma, G., Wan, D. L. Y., & Muselin, G. (2018). Development of high-performance self-compacting concrete using waste recycled concrete aggregates and rubber granules. *Journal of Cleaner Production*, *182*, 553-566.

ASTM C109/C109M-16a. (2016). Standard Test Method for Compressive Strength of hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens), *ASTM International*, West Conshohocken, United States.

ASTM C136/C136M-19. (2019). Standard Test Method for Sieve Analysis of Fine and Coarse Aggregate, *ASTM International*, West Conshohocken, United States.

ASTM C1611/C1611M-18. (2018). Standard Test Method for Slump Flow of Self-Consolidating Concrete, *ASTM International*, West Conshohocken, United States.

ASTM C642-13. (2013). Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, *ASTM International*, West Conshohocken, United States.

ASTM C936/C936M-21. (2021). Standard Specification for Solid Concrete Interlocking Paving Units, *ASTM International*, West Conshohocken, United States.

Bala, A., & Gupta, S. (2021). Thermal resistivity, sound absorption and vibration damping of concrete composite doped with waste tire Rubber: A review. *Construction and Building Materials*, *299*, 123939.

Benazzouk, A., Mezreb, K., Doyen, G., Goullieux, A., & Quéneudec, M. (2003). Effect of rubber aggregates on the physico-mechanical behaviour of cement–rubber composites-influence of the alveolar texture of rubber aggregates. *Cement and Concrete Composites*, *25*(7), 711-720.

Diaz-Loya, E. I., Allouche, E. N., & Vaidya, S. (2011). Mechanical properties of fly-ash-based geopolymer concrete. *ACI materials journal*, *108*(3), 300.

Dong, M., Elchalakani, M., Karrech, A., & Yang, B. (2021). Strength and durability of geopolymer concrete with high volume rubber replacement. *Construction and Building Materials*, *274*, 121783.

Hwang, C. L., & Huynh, T. P. (2015). Effect of alkali-activator and rice husk ash content on strength development of fly ash and residual rice husk ash-based geopolymers. *Construction and Building Materials*, *101*, 1-9.

Jindal, B. B. (2019). Investigations on the properties of geopolymer mortar and concrete with mineral admixtures: A review. *Construction and building materials*, *227*, 116644.

Kong, D. L., & Sanjayan, J. G. (2010). Effect of elevated temperatures on geopolymer paste, mortar and concrete. *Cement and concrete research*, *40*(2), 334-339.

Lv, J., Zhou, T., Du, Q., & Wu, H. (2015). Effects of rubber particles on mechanical properties of lightweight aggregate concrete. *Construction and Building Materials*, *91*, 145-149.

Mohsin, A. I., & Fahad, B. M. (2015). Improve the acoustic impedance and thermal conductivity of mortar by adding recycled rubber. *Journal of Modern Engineering Research*, *5*, 9-16.

Moustafa, A., & ElGawady, M. A. (2015). Mechanical properties of high strength concrete with scrap tire rubber. *Construction and Building Materials*, *93*, 249-256.

Muñoz-Sánchez, B., Arévalo-Caballero, M. J., & Pacheco-Menor, M. C. (2017). Influence of acetic acid and calcium hydroxide treatments of rubber waste on the properties of rubberized mortars. *Materials and Structures*, *50*(1), 1-16.

Nuaklong, P., Janprasit, K., & Jongvivatsakul, P. (2021b). Enhancement of strengths of high-calcium fly ash geopolymer containing borax with rice husk ash. *Journal of Building Engineering*, *40*, 102762.

Nuaklong, P., Worawatnalunart, P., Jongvivatsakul, P., Tangaramvong, S., Pothisiri, T., & Likitlersuang, S. (2021a). Pre-and post-fire mechanical performances of high calcium fly ash geopolymer concrete containing granite waste. *Journal of Building Engineering*, *44*, 103265.

Park, Y., Abolmaali, A., Kim, Y. H., & Ghahremannejad, M. (2016). Compressive strength of fly ash-based geopolymer concrete with crumb rubber partially replacing sand. *Construction and Building Materials*, *118*, 43-51.

Pham, T. M., Elchalakani, M., Hao, H., Lai, J., Ameduri, S., & Tran, T. M. (2019). Durability characteristics of lightweight rubberized concrete. *Construction and Building Materials*, *224*, 584-599.

Pham, T. M., Lim, Y. Y., & Malekzadeh, M. (2021). Effect of pre-treatment methods of crumb rubber on strength, permeability and acid attack resistance of rubberised geopolymer concrete. *Journal of Building Engineering*, *41*, 102448.

Sharaky, I. A., Mohamed, H. A., Torres, L., & Emara, M. (2020). Flexural behavior of rubberized concrete beams strengthened in shear using welded wire mesh. *Composite Structures*, *247*, 112485.

Sodupe-Ortega, E., Fraile-Garcia, E., Ferreiro-Cabello, J., & Sanz-Garcia, A. (2016). Evaluation of crumb rubber as aggregate for automated manufacturing of rubberized long hollow blocks and bricks. *Construction and Building materials*, *106*, 305-316.

Youssf, O., Hassanli, R., & Mills, J. E. (2017). Mechanical performance of FRP-confined and unconfined crumb rubber concrete containing high rubber content. *Journal of Building Engineering*, *11*, 115-126.

Pisit Thongjub is a student at the Department of Civil Engineering, Thammasat University, Thailand. He got a Bachelor's degree in Civil Engineering from Southeast Asia University, Thailand. His researches are Construction Material and Pavement Applications such as Interlocking Paving Block Technology.

Dr. Peem Nuaklong is a Lecturer at the Department of Civil Engineering, Thammasat University, Thailand. He got his Master's and PhD degrees in Civil Engineering from Khon Kaen University, Thailand. His research focuses on Concrete Technology.

Dr. Pitcha Jongvivatsakul is an Associate Professor at the Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand. She got her Master's and PhD degrees in Civil Engineering from the Tokyo Institute of Technology, Japan. Her research focuses on Innovation in Construction Materials and Strengthening of Concrete Structures.

Dr. Nareenart Raksuntorn is an Assistant Professor at the Faculty of Industrial Technology, Suan Sunandha Rajabhat University. She received a B.Eng. degree in Electronics Engineering from King Mongkut's Institute of Technology Ladkrabang, Thailand, an M.S. degree in Electrical Engineering from the University of Colorado, and a Ph.D. degree in Electrical Engineering from the Department of Electrical and Computer Engineering, Mississippi State University. Her research interests include Remote Sensing Image Analysis, Image Processing, and Pattern Recognition.

Dr. Boonsap Witchayangkoon is an Associate Professor of Department of Civil Engineering at Thammasat University. He received his B.Eng. from King Mongkut's University of Technology Thonburi with Honors. He earned his PhD from University of Maine, USA in Spatial Information Science & Engineering. Dr. Witchayangkoon interests involve Applications of Emerging Technologies to Engineering.

Dr. Winai Raksuntorn received his PhD (Civil Engineering) from the University of Colorado, USA. He is an Assistant Professor in the Department of Civil Engineering, Faculty of Engineering, Thammasat University. His research interests include Transportation Safety Analysis, Traffic Operations and Management, Traffic Impact Studies, Traffic Flow Modeling Highway Capacity Analysis, Advanced Traffic Management for Intelligent Transportation Systems.

Dr. Sayan Sirimontree earned his bachelor's degree from Khon Kaen University Thailand, master's degree in Structural Engineering from Chulalongkorn University Thailand and PhD in Structural Engineering from Khon Kaen University Thailand. He is an Associate Professor at Thammasat University Thailand. He is interested in Durability of Concrete, Repair and Strengthening of Reinforced and Prestressed Concrete Structures.