International Journal of GEOMATE, Feb., 2023, Vol.24, Issue 102, pp.109-116
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.102.s8596
Geotechnique, Construction Materials and Environment

LABORATORY STUDY OF PHYSICAL AND THERMAL PROPERTIES OF CONCRETE MIXED WITH BAKELITE

Sitthiphat Eua-apiwatch[1] and *Worasit Kanjanakijkasem[2]

[1]Department of Civil Engineering, Faculty of Engineering, Burapha University, Thailand;
[2]Department of Mechanical Engineering, Faculty of Engineering, Burapha University, Thailand

*Corresponding Author, Received: 11 June 2022, Revised: 26 Dec. 2022, Accepted: 25 Jan. 2023

ABSTRACT: This research aims to study the physical and thermal properties of concrete blocks mixed with Bakelite. The main goal of this research is to use Bakelite plastic to replace the total mass of concrete blocks. The laboratory tests include compressive strength test, density test, water absorption test, and thermal conductivity test. The concrete blocks are mixture of Portland cement type one, dust stone, sand, and Bakelite plastic. The mixing ratio of concrete blocks with a binder to total mass is 1:5 by weight. The percentage of Bakelite plastic varies from 0% to 20% and the curing method of concrete blocks is air curing for 7, 14, and 28 days. The compressive strength and density tests were conducted after the completion of each curing period, while the water absorption test was conducted only for the curing period of 28 days. Two groups of concrete block samples, 50x50x50 mm^3 were used in the physical properties tests, while 100x100x100 mm^3 concrete block samples with the curing period of 28 days were used in the thermal conductivity test. The result shows that an increasing in the percentage of Bakelite decreases the compressive strength and density of concrete block samples. The water absorption is in proportion to the increasing of percentage of Bakelite. Finally, an increasing of Bakelite ranging from 0% to 20% roughly reduces the thermal conductivity of concrete block samples from 0.5 W/m-K to 0.3 W/m-K.

Keywords: Bakelite plastic, Compressive strength, Density, Water absorption, Thermal conductivity

1. INTRODUCTION

The total amount of plastic waste generated in Thailand is approximately 2 million tons per year, and only about 0.5 million tons per year can be recycled. The remaining 1.5 million tons is a single-used plastic and cannot be recycled. Most of them will be disposed of as solid waste and continuously increasing. In 2020, a study on the amount of plastic waste [1] stated that there was approximately 6,300 tons of plastic waste per day during the coronavirus disease 2019 epidemic, or a 15% increase in plastic waste compared to the same period under normal circumstances in 2019. Due to the epidemic situation, people have changed their behaviors in using online shopping services coupled with less waste sorting for recycling due to fear of infectious waste that was mixed with community solid waste.

Bakelite, developed by Leo Baekeland in 1907, is one of plastic that causes difficulties in waste treatment. It has played more important role in the industry because it can be manufactured with less effort and its cost is low. While its properties such as low thermal conductivity and electrical conductance can satisfy various requirements of several products. To eliminate the Bakelite waste, it is prohibited from direct disposed to the landfilling and open burning [2]. Therefore, the cost of Bakelite waste treatment is very high.

Several researchers have investigated on the utilization of solid waste to be replaced of concrete aggregate in construction materials, e.g. Tuprakay et al. [3], Rani et al. [4], and Mohamad et al. [5]. Most of them are focusing on either physical properties or thermal properties. While the study investigating on both physical and thermal properties of concrete that using solid waste as an aggregate, especially plastic waste, still being lacked.

For the physical issue of concrete using plastic waste as an aggregate, Dinesh et al. [6] had studied the mechanical properties of paving bricks mixed with high-density polyethylene, which its density is very close to that of Bakelite. This plastic is widely used in the industry and causes many landfill and incineration problems. The preparation and testing were performed by adding plastic to the mix with the ratios of 1:2 to 1:6 of the initial road brick mixture and then compared with the road bricks mixed with fly ash and clay bricks. The study found that the compressive strength of fly ash bricks was 4.19 MPa, that of clay bricks was 3.15 MPa, and plastic sand bricks give the highest strength was 1:4 at 5.12 MPa.

Singh et al. [7] utilized the plastic waste in civil engineering by using crushed CD and plastic bottles to be replaced of aggregate in the bricks. The mixing ratio of plastic waste and sand is 1:1.5 by weight, and the compressive strength test found that CD bricks and PB bricks had compressive strengths of 10 and 10.6 MPa, respectively, which had higher compressive strength than standard clay bricks.

Furthermore, it has lower water absorption and porosity than standard clay bricks.

Usahanunth et al. [8] had studied the utilization of Bakelite plastic waste as a substitute for natural aggregates sand in producing concrete and mortar. It was found that replacing 20% of natural coarse aggregate with waste Bakelite coarse aggregate was the most suitable for application because of its mechanical properties, safety for environment, safety for public health, and acceptable cost. In contrast, the use of waste Bakelite fine aggregate to replace natural fine aggregate was not recommended because its strength was decreased below the strength of the ordinary concrete which is considered unsafe.

Li and Kaewunruen [9] evaluated the possibility of using the recycled plastic concrete in railway track application by replacing natural coarse aggregate by 3.35 mm, 5.6 mm, and mixed size recycled plastic. The results revealed that an increase of the plastic aggregate improved the workability of the recycled concrete in railway track application. The electrical resistance and vibration energy absorption were also improved.

Chusilp and Laksanakit [10] investigated the effects of recycled high-density polyethylene plastic granules as a replacement of fine aggregate on the mechanical and durability properties of concrete. It was found that using of high-density polyethylene caused a reduction in mechanical and durability properties. However, the 20% of filler replacement still presented an acceptable compressive strength in according to the Thai Industrial Standard (TIS) No. 57-2530 for compressive strength of hollow load-bearing concrete masonry units at 5.5 MPa.

Adajar and Ubay-Anongphouth [11] conducted a study of incorporating polyethylene terephthalate plastics (PET) into fly ash concrete to investigate their effects on compressive and flexural strengths. The 30% fly ash concrete was used as specimens, which were prepared and tested following ASTM standards, while the amount of polyethylene terephthalate plastics was varied from 0% to 15%. It was found that the inclusion of polyethylene terephthalate plastics in fly ash concrete can result in an increase in workability, a decrease in unit weight, and an improvement in compressive and flexural strengths.

For the thermal issue of concrete using plastic waste as an aggregate, Girardi [12] conducted thermal conductivity testing according to the ASTM C518 standard using smaller samples of six commercial insulation materials and correlated the results to those obtained by using standard size samples. It was reported that the method can measure thermal conductivity accurately for samples of 200x200 mm, 150x150 mm, and 100x100 mm; while the results from 50x50 mm samples were not reliable. Also, the results were analyzed using the finite element tool, HEAT3.

Bai et al. [13] investigated the thermal properties of hollow shale blocks and walls. The experimental heat transfer coefficient of 0.726 W/m^2-K and the theoretical heat transfer coefficient of 0.546 W/m^2-K were reported. The one-dimensional steady heat conduction of the block and walls was simulated using ANSYS and the heat transfer coefficient for the walls of 0.671 W/m^2-K was predicted which showed a good agreement with the experimental results.

In this study, Bakelite are used as an element of aggregate for concrete block forming to be an approach to reduce Bakelite waste. Basic physical properties including compressive strength, density, and water absorption of concrete block samples mixed with Bakelite ranging from 0% to 20% are investigated. Thermal conductivity is also tested and reported for all mixtures used in the physical property testing with the curing period of 28 days to implement the coordination of numerical technique, i.e. numerical differentiation via the method of undetermined coefficients, with the experimental data. The obtained physical and thermal properties can be treated as basic information for using such concrete blocks as a construction material.

2. MATERIAL AND ITS PROPERTIES

2.1 Bakelite

Bakelite is the commercial name of a thermosetting phenol formaldehyde resin formed from the condensation reaction of phenol with formaldehyde. Its main chemical components consist of carbon, hydrogen, and oxygen. Compounds found in Bakelite by X-Ray diffraction (XRD) technique are reported in Table 1 which calcium oxide is the main compound with a small amount of silica and sulfur trioxide. The specific gravity of Bakelite used in this study is ranging from 1.3 to 1.4. The Bakelite used in this study is red dyed obtained from lathe machine and considerate as industrial waste.

Table 1 Chemical compounds in Bakelite.

Compound	Percentage by weight (%)
CaO	94.23
SiO_2	5.14
SO_3	0.33

2.2 Aggregate

Quarry dust, sand, and ordinary Portland cement type 1 used in forming concrete blocks have specific gravity of 2.70, 2.65, and 3.13, respectively. The particle size distribution of quarry dust is shown in Fig. 1.

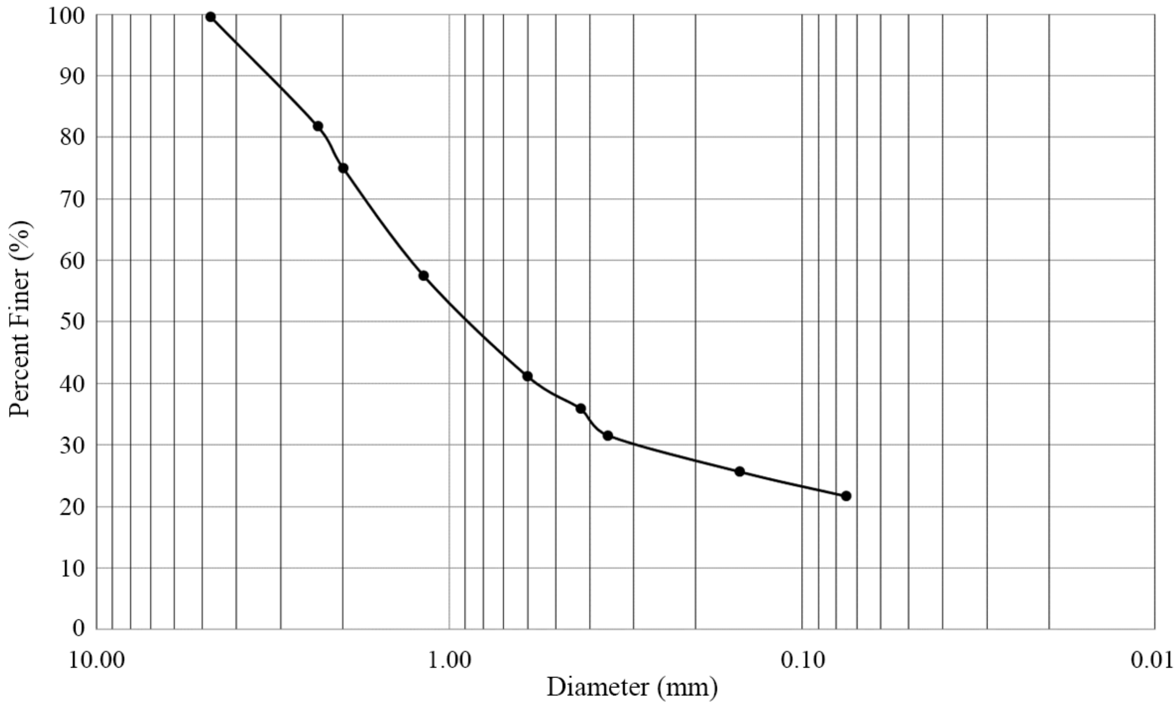
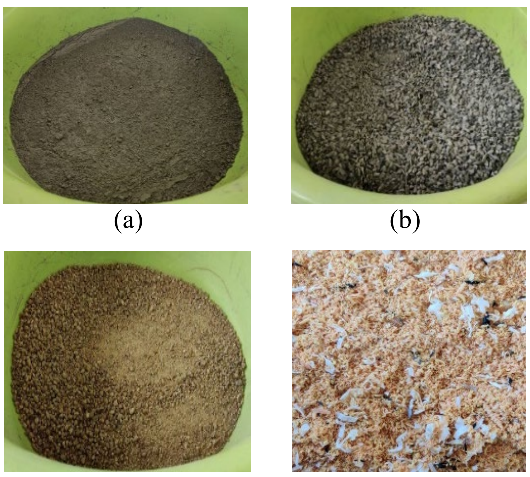


Fig. 1 Particle size distribution of quarry dust.

3. METHODOLOGY

3.1 Physical Properties Testing

Physical property testing includes compressive strength testing, density testing, and water absorption testing. Concrete blocks sample for all tests were prepared using one kilogram of Portland cement type 1 mixed with quarry dust, sand, and Bakelite shown in Fig. 2. The mixtures of concrete block samples are shown in Fig. 2.



(a) (b) (c) (d)

Fig. 2 Materials use in the study including (a) Portland cement (b) quarry dust (c) sand (d) Bakelite plastic.

CINVA-Ram block press machine which is developed by Raul Ramirez at the Inter-American Housing Center in 1956 shown in Fig. 3 was using in preparation of concrete block samples. Concrete blocks samples were formed with a dimension of 100x1250x250 mm^3 as shown in Fig. 4.

Fig. 3 CINVA-Ram block press machine.

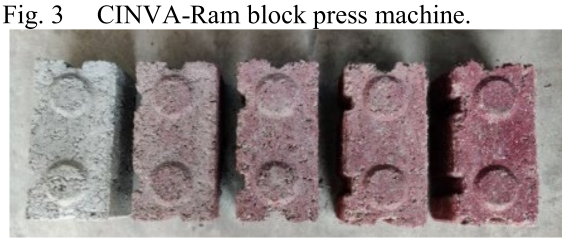


Fig. 4 Sample of concrete blocks

Table 2 Mixtures of concrete block samples.

No.	Mass (kg)		Fine Bakelite plastic (kg)	Water (cc.)
	Quarry Dust (kg)	Sand (kg)		
1	4.00	1.00	0	800
2	3.80	0.95	0.25	900
3	3.60	0.90	0.50	1000
4	3.40	0.85	0.75	1100
5	3.20	0.80	1.00	1200

The concrete blocks were cured in the air for 7, 14, and 28 days. After the curing period, they were cut into concrete block samples with dimensions of 50x50x50 mm^3 as shown in Fig. 5 for physical properties testing.

For each mixture, five concrete block samples were tested. Firstly, their densities were found. Then, they were dried at a temperature ranging from 105°C to 110°C and immersed in water for 24 hours to find water absorption. Finally, the compressive strengths of concrete block samples were tested by a concrete compression machine.

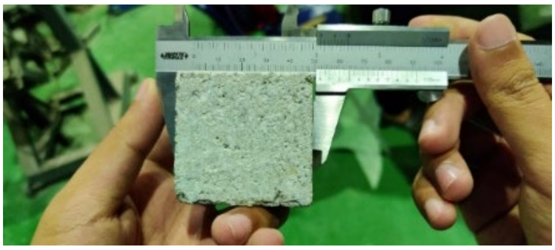


Fig. 5 Concrete blocks for physical properties testing.

3.2 Thermal Conductivity Testing

The mixtures of concrete blocks in the physical properties testing are also used in thermal conductivity testing. The dimension of concrete block samples for this purpose is 100x100x100 mm^3 with a curing period of 28 days and three concrete block samples are employed for each mixture. Five thermocouples of type K, calibrated at the melting point and boiling point of distilled water, were placed on the middle plane of the concrete block sample and equally spaced along the vertical line passing through its centroid as shown in Fig. 6.

In Fig. 7, the concrete block sample was three-layer insulated on all vertical surfaces and on top surface (not shown) to prevent heat losses to ambient air. On the top surface, a heat flux sensor was placed at its centroid. After assembling all stuff, it was heated from the bottom surface by a compact heater.

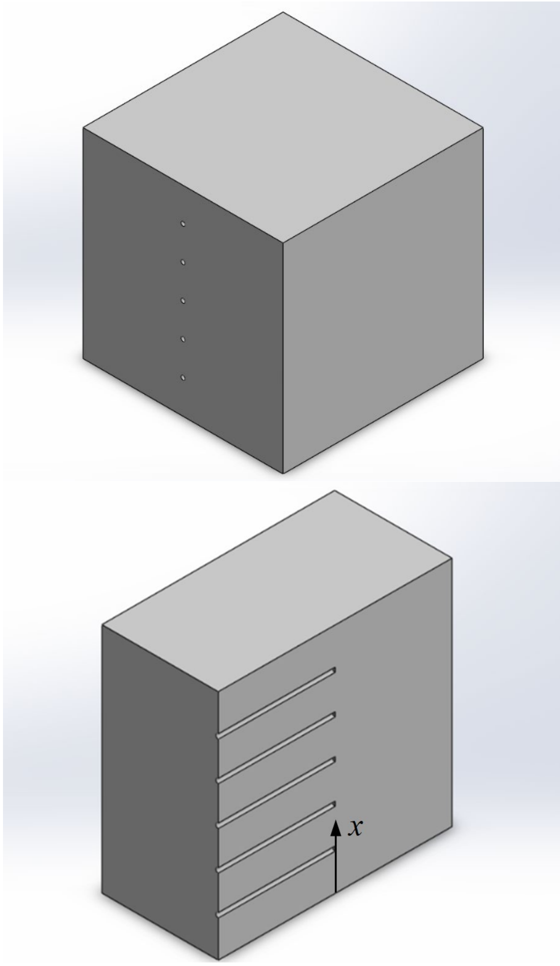


Fig. 6 Locations of thermocouple installation.

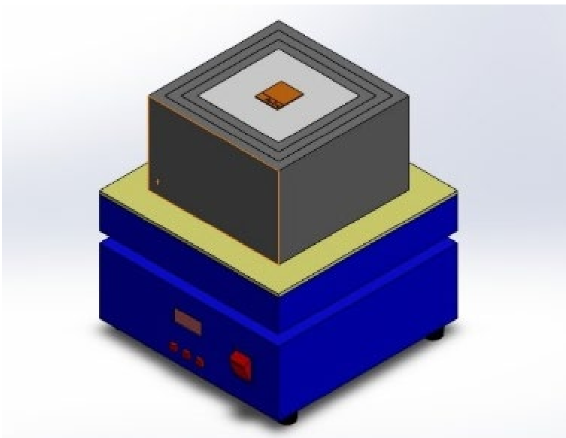


Fig. 7 Heating of concrete block samples.

Placing of all thermocouples as explained above results in obtaining temperature distribution along the vertical line passing through the centroid of the concrete block sample which can be considered as one-dimensional conduction heat transfer. The Temperature gradient at steady state, $\frac{dT}{dx}$, can be computed from temperatures at five locations, while the corresponding heat transfer rate on the top surface, q_x, can be obtained from the heat flux sensor. Consequently, the thermal conductivity of the concrete block sample, k, can be computed from Fourier's law of conduction [14] in Eq.(1).

$$q_x = -k \cdot \frac{dT}{dx} \tag{1}$$

$$f'(x) = a \cdot f(x_1) + b \cdot f(x_2) + c \cdot f(x_3) + d \cdot f(x_4) + e \cdot f(x_5) \tag{2}$$

$$\begin{aligned} f'(x) = {} & a \cdot \left[f(x) + f'(x) \cdot (x_1 - x) + \tfrac{1}{2!} \cdot f''(x) \cdot (x_1 - x)^2 + \tfrac{1}{3!} \cdot f^{(3)}(x) \cdot (x_1 - x)^3 + \tfrac{1}{4!} \cdot f^{(4)}(x) \cdot (x_1 - x)^4 + \ldots \right] \\ & + b \cdot \left[f(x) + f'(x) \cdot (x_2 - x) + \tfrac{1}{2!} \cdot f''(x) \cdot (x_2 - x)^2 + \tfrac{1}{3!} \cdot f^{(3)}(x) \cdot (x_2 - x)^3 + \tfrac{1}{4!} \cdot f^{(4)}(x) \cdot (x_2 - x)^4 + \ldots \right] \\ & + c \cdot \left[f(x) + f'(x) \cdot (x_3 - x) + \tfrac{1}{2!} \cdot f''(x) \cdot (x_3 - x)^2 + \tfrac{1}{3!} \cdot f^{(3)}(x) \cdot (x_3 - x)^3 + \tfrac{1}{4!} \cdot f^{(4)}(x) \cdot (x_3 - x)^4 + \ldots \right] \\ & + d \cdot \left[f(x) + f'(x) \cdot (x_4 - x) + \tfrac{1}{2!} \cdot f''(x) \cdot (x_4 - x)^2 + \tfrac{1}{3!} \cdot f^{(3)}(x) \cdot (x_4 - x)^3 + \tfrac{1}{4!} \cdot f^{(4)}(x) \cdot (x_4 - x)^4 + \ldots \right] \\ & + e \cdot \left[f(x) + f'(x) \cdot (x_5 - x) + \tfrac{1}{2!} \cdot f''(x) \cdot (x_5 - x)^2 + \tfrac{1}{3!} \cdot f^{(3)}(x) \cdot (x_5 - x)^3 + \tfrac{1}{4!} \cdot f^{(4)}(x) \cdot (x_5 - x)^4 + \ldots \right] \end{aligned} \tag{3}$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ x_1 - x & x_2 - x & x_3 - x & x_4 - x & x_5 - x \\ \tfrac{1}{2!} \cdot (x_1 - x)^2 & \tfrac{1}{2!} \cdot (x_2 - x)^2 & \tfrac{1}{2!} \cdot (x_3 - x)^2 & \tfrac{1}{2!} \cdot (x_4 - x)^2 & \tfrac{1}{2!} \cdot (x_5 - x)^2 \\ \tfrac{1}{3!} \cdot (x_1 - x)^3 & \tfrac{1}{3!} \cdot (x_2 - x)^3 & \tfrac{1}{3!} \cdot (x_3 - x)^3 & \tfrac{1}{3!} \cdot (x_4 - x)^3 & \tfrac{1}{3!} \cdot (x_5 - x)^3 \\ \tfrac{1}{4!} \cdot (x_1 - x)^4 & \tfrac{1}{4!} \cdot (x_2 - x)^4 & \tfrac{1}{4!} \cdot (x_3 - x)^4 & \tfrac{1}{4!} \cdot (x_4 - x)^4 & \tfrac{1}{4!} \cdot (x_5 - x)^4 \end{bmatrix} \begin{Bmatrix} a \\ b \\ c \\ d \\ e \end{Bmatrix} = \begin{Bmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{Bmatrix} \tag{4}$$

The Temperature gradient along the vertical line passing through the centroid of the concrete block sample can be computed via the method of undetermined coefficients [15]. It starts by writing the first derivative of a function at any point, x, as a summation of the weighted of that function at five points in Eq.(2). Then, all terms on the right-hand side are replaced by Taylor series expansion about a point, x, as in Eq.(3). Finally, a system of equations in Eq.(4) is set up from the coefficients of the first five terms of all series, i.e., the coefficients of $f(x)$, $f'(x), f''(x), f^{(3)}(x), f^{(4)}(x)$. This can yield the formula for numerical differentiation after obtaining all weighting factors from the system of equations. After putting the location, x, of the top surface into the formula, the temperature gradient can be immediately computed. It should be noted that the locations of thermocouples will be a part of the input for this approach, so it is not necessary to be seriously concerned about precision in equally spacing them.

However, the locations of thermocouples are decided to be equally spaced along 100-mm length of the line passing centroid of the concrete block sample. Consequently, all the locations that are input in Eq. (4) are x_1=16.7 mm, x_2=33.3 mm, x_3=50.0 mm, x_4=66.7 mm, and x_5=83.3 mm. The location where the temperature gradient is estimated is x=100.0 mm.

4. RESULTS AND DISCUSSIONS

The concrete blocks samples with percentage of plastic varies from 0% to 20% and air curing for 7, 14, and 28 days were test in the laboratory including compressive strength test, density test, water absorption test, and thermal conductivity test. The test results are as follows.

4.1 Physical Properties

The compressive strength of the concrete block sample without mixing of Bakelite with a curing period of 28 days is 261 ksc which is the highest compressive strength of the concrete block sample in this study. The compressive strength of concrete block samples increased with respect to the curing period but decreased with respect to the percentage of Bakelite by weight as presented in Fig. 8.

The density of concrete block samples decreased with respect to the percentage of Bakelite. This resulted from several tiny voids that occurred after the setting of concrete block samples. The curing period of 28 days which is the longest curing period in this study seems to yield the lowest density of concrete block samples for all mixtures. While the curing period of 7 and 14 days tends to yield a comparable density of concrete block samples and is higher than that of concrete block samples with a curing period of 28 days.

The water absorption of concrete block samples increased with respect to percentage of Bakelite. This is because higher percentage of Bakelite had caused the concrete block samples to have higher porosity from the expansion of Bakelite due to the hydration reaction of cement and water. The lowest absorption is at 9% for the concrete block sample with no mixing of Bakelite.

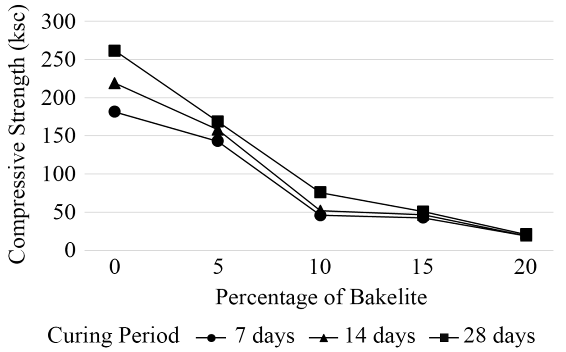


Fig. 8 Relationship between compressive strength and percentage of Bakelite.

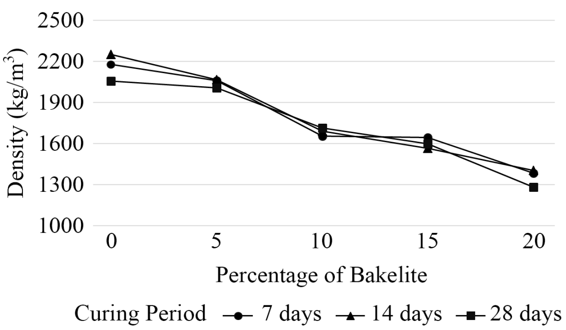


Fig. 9 Relationship between density and percentage of Bakelite.

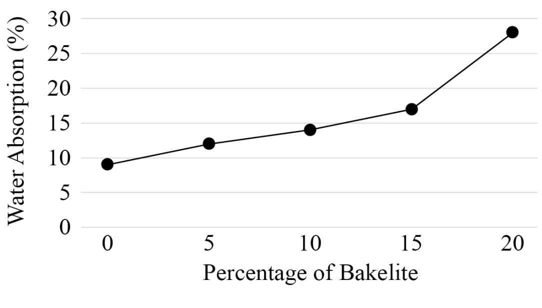


Fig. 10 Relationship between water absorption and percentage of Bakelite.

4.2 Thermal Conductivity

Three concrete block samples with curing period of 28 days were tested for each mixture. Each case was lasting about 3 to 8 hours to reach steady state of heat conduction, i.e., the temperature of the location closest to the heater was constant about 10 minutes. This location was selected because it could have largest temperature change from room temperature. Or it can be said that the temperature at this location is the most sensitive one among all five locations. Although the precision in placing all thermocouples was not the issue to be concerned, they were equally spaced in this study and all the results are shown in Table 3. The format of sample name is the combination of the percentage of Bakelite and number of samples, e.g., sample 0-1 means sample number 1 of concrete block with 0% of Bakelite, etc.

Thermal conductivities of all concrete block samples computed from temperature gradients and heat fluxes in Table 3 are presented in Table 4 and as bar chart in Figure 9. It was roughly found that thermal conductivities of concrete block samples linearly decreased from 0.5 W/m-K to 0.3 W/m-K with respect to the percentage of Bakelite ranging from 0% to 20%.

5. CONCLUSIONS

Physical properties testing and thermal conductivity testing of concrete mixed with Bakelite are carried out in this study. The experimental results reveal that the increasing in the percentage of Bakelite bring about the decreasing in compressive strength and density of the concrete block samples, while the water absorption of the concrete block samples is heightened. Additionally, the increasing of Bakelite ranging from 0% to 20% roughly reduces the thermal conductivity of the concrete block samples from 0.5 W/m-K to 0.3 W/m-K.

6. ACKNOWLEDGMENTS

This research is partly supported by the Research Fund No. PJ 6/2563 from Faculty of Engineering, Burapha University.

7. REFERENCES

[1] Pollution Control Department, Situation of Municipal solid waste in Thailand, 2021 (in Thai).

[2] Frias J.P.G.L. and Nash R., Microplastics: Finding a consensus on the definition, Marine Pollution Bulletin., Vol.138, 2019, pp. 145-147.

[3] Tuprakay S., Usahanunth N., and Tuprakay S.R., A study Bakelite plastics waste from industrial process in concrete products as aggregate, International Journal of Structural and Civil Engineering Research., Vol.6, 2017, pp. 263-267.

Table 3 Temperature distributions along the line passing through the centroid of concrete block samples and temperature gradients at the top surface of concrete block samples.

Sample	Temperature (˚C) at Locations along x-axis					dT/dx	$q_x \pm 2$S.D.
	1.67 cm	3.33 cm	5.00 cm	6.67 cm	8.33 cm	$(\frac{\mathrm{K}}{\mathrm{m}})$	$(\frac{\mathrm{W}}{\mathrm{m}^2})$
0-1	79.212	72.730	70.050	67.895	64.486	-258.369	136.820 ± 0.639
0-2	76.725	71.430	69.415	67.568	64.610	-211.506	113.216 ± 0.370
0-3	78.530	73.400	70.697	68.440	65.640	-191.981	97.740 ± 0.385
5-1	78.553	74.790	42.546	70.309	64.456	-191.427	88.700±0.402
5-2	78.520	72.955	70.790	68.653	65.715	-181.545	83.020±0.379
5-3	77.208	72.780	69.200	66.747	63.980	-232.899	107.320±0.485
10-1	77.670	73.594	69.140	66.587	63.550	-317.369	129.382±0.494
10-2	76.963	74.355	70.481	67.790	65.065	-246.627	97.797±0.445
10-3	76.937	72.408	69.012	66.899	64.427	-221.367	90.460±0.315
15-1	76.383	72.584	67.290	63.882	60.947	-265.49	90.992±0.313
15-2	76.961	72.338	67.170	64.960	62.520	-320.081	112.963±0.410
15-3	77.789	72.932	68.190	65.950	63.700	-261.65	90.991±0.233
20-1	74.772	68.445	66.676	64.943	60.427	-388.442	112.963±0.420
20-2	76.382	69.870	66.013	63.400	60.154	-261.591	83.291±0.303
20-3	73.690	68.619	64.910	61.921	58.051	-308.610	95.997±0.363

Table 4 Thermal conductivity of concrete block samples.

Percentage of Bakelite (%)	Thermal Conductivity $(\frac{\mathrm{W}}{\mathrm{m{\cdot}K}})$		
	Sample 1	Sample 2	Sample 3
0	0.529553 ± 0.002473	0.535286 ± 0.001751	0.509113 ± 0.002023
5	0.463362 ± 0.002100	0.457297 ± 0.002087	0.460801 ± 0.002083
10	0.407671 ± 0.001556	0.396538 ± 0.001804	0.408643 ± 0.001424
15	0.342732 ± 0.001179	0.352920 ± 0.001280	0.347758 ± 0.000891
20	0.290810 ± 0.001082	0.318402 ± 0.001580	0.311063 ± 0.001770

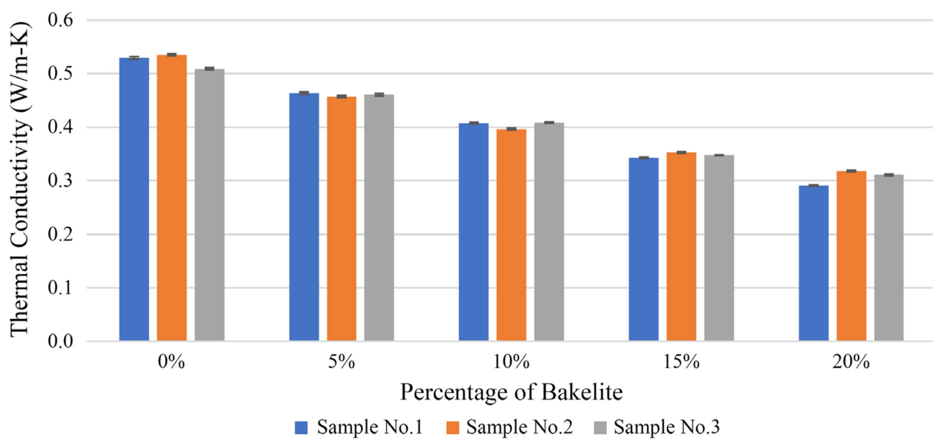


Fig. 11 Bar chart of thermal conductivity of concrete block samples.

[4] Rani G.Y., Krishna T.J., and Murali K., Strength studies on effect of glass waste in concrete, Materials Today: Proceedings, Vol.46, 2021, pp. 8817-8821.
[5] Mohamad H.M., Bolong N., Sadd I., Gungat L., Tioon J., Pileh R., and Delton M., Manufacture of Concrete Paver Block Using Waste Materials and By-Products: A Review, International Journal of GEOMATE, Vol.22, Issue 93, 2022, pp.9-19.
[6] Dinesh S., Dinesh A., and Kirubakaran K., Utilization of waste plastic in manufacturing of bricks and paver blocks, International Journal of Applied Engineering Research, Vol. 11, No.3, 2016, pp. 364-368.
[7] Singh L.B., Singh L.G., Singh P.B., and Thokchom S., Manufacturing bricks from Sand and Waste Plastics, International Journal of Engineering Technology, Management and Applied Sciences, Volume 5, Issue 3, 2017, pp. 426-428.
[8] Usahanunth N., Tuprakay S., Kongsong W., and Tuprakay S.R., Study of mechanical properties and recommendations for the application of Waste Bakelite aggregate concrete, Case Studies in Construction Materials., Vol.8, 2018, pp. 299–314.
[9] Li D. and Kaewunruen, Mechanical Properties of Concrete with Recycled Composite and Plastic Aggregates, International Journal of GEOMATE, Vol.17, Issue 60, 2019, pp.231-238.
[10] Chusilp N. and Laksanakit C., Effect of Recycled Plastic Content as Fillers on Mechanical and Durability Properties of Concrete, International Journal of GEOMATE, Vol.22, Issue 92, 2022, pp.56-63.
[11] Adajar M.A. and Ubay-Anongphouth I.O., Effects of Polyethylene Terephthalate (PET) Plastics on the Mechanical Properties of Fly Ash Concrete, International Journal of GEOMATE, Vol.23, Issue 95, 2022, pp.162-167.
[12] Girardi G., Measurement of Thermal Conductivity of Smaller Thermal Insulations Specimens Using Standard Heat Flow Meter Apparatus, Master Thesis, Department of Civil and Environmental Engineering, Carleton University, 2013, pp1-116.
[13] Bai, G.-L., Du N.-J., Xu Y.-Z., and Qin C.-G., Study on the Thermal Properties of Hollow Shale Blocks as Self-Insulating Wall Materials, Advances in Materials Science and Engineering, 2017, pp. 1-12.
[14] Incropera F.P., DeWitt D.P., Bergmann T.L., and Lavine A.S., Fundamentals of Heat and Mass Transfer, 6th ed., John Wiley & Sons, U.S.A., 2007, pp. 3-5.
[15] Kanjanakijkasem W., Numerical Methods, 2nd ed., Charansanitwong Printing, Bangkok, Thailand, 2020 (in Thai), pp. 193-211.