International Journal of Applied Science and Engineering

The feasibility of eco-concrete mixed with used plastic bottles to replace coarse aggregate for construction in Thailand community

Jaran Ratanachotinun*

Civil and Construction Management Engineering, Faculty of Science, Chandrakasem Rajabhat University Bangkok 10900 Thailand

ABSTRACT

This research is to study the feasibility of eco-concrete mixed with used plastic bottles to replace coarse aggregate (ECP) for construction community in Thailand. Compressive strength test between typical concrete and eco-concrete mixed with plastic water bottles to replace all coarse aggregate (ECPA) in ratios of 5%, 10%, 15% and 17% by weight of cement and eco-concrete mixed with plastic water bottles to replace some coarse aggregate (ECPS) in the ratio of 5%, 10%, 15%, 20%, 25% and 30% by coarse aggregate weight which recuring time of concrete at 7, 14 and 28 days. The results showed that the proportion of used plastic bottles (PET) and the compressive strength for ECPA and ECPS is not more than 5%. of cement weight and 10% of coarse aggregate weight respectively, the average compressive strength was approximately 225 and 217 kg/cm^2 respectively. The cost of ECPA and ECPS is approximately 122.73 USD/m^3 or approximately 98.7% more than the cost of typical concrete and 58.73 USD/m^3 or about 5% lower than the typical concrete cost respectively. Construction applications for Thailand communities are practical and promoting the use of ECP can help reduce CO_2 emissions from plastic waste disposal by at least 147,300 kg/year.

Keywords: Concrete mixed with plastic, Concrete cost, Used plastic bottles, Eco-Concrete, CO_2.

OPEN ACCESS

Received: August 17, 2022
Revised: November 29, 2022
Accepted: January 21, 2023

Corresponding Author:
Jaran Ratanachotinun
jaran.r@chandra.ac.th

Publisher:
Chaoyang University of Technology
ISSN: 1727-2394 (Print)
ISSN: 1727-7841 (Online)

1. INTRODUCTION

Concrete is a material used in civil engineering and infrastructure construction. The composition of concrete consists of cement, stone, sand, water and concrete admixtures, when mixed, it transforms into a solid and has great compressive strength. The cost of raw materials used in the concrete mix will also have a higher cost according to the design efficiency of the specified load. Reducing concrete mixes while maintaining an acceptable load-bearing performance can save concrete costs. The use of plastics is a problem that affects the environment by producing and disposing of waste plastics that create more pollution. According to the data by Bank of Ayudhya Public Company Limited (2021) explains the total concrete consumption for construction in Thailand in 2020 is 23 million cubic meters per year and is divided into approximately 45% of the use of the residential sector, indicating that the use of concrete for residential construction is about 10 million cubic meters. The study of cool down our beloved Earth together with the Bangkok Metropolitan Administration, Thailand by JICA: Japan International Cooperation Agency (2010) explains the environmental impact show that reducing 1 kg of plastic waste reduces CO_2 from waste disposal by approximately 0.3 kg. Changing the disposal of environmentally-affected plastic drinking water bottles to using recycled plastic water bottles in construction concrete is an approach that can help save the environment as well as feasibility to reduce the cost of concrete for construction in Thailand community. Research related to the sustainable building design study for Thailand such as a design and assessment of solar chimney of bioclimatic house wall and roof for construction in the housing market of Thailand by Ratanachotinun et al. (2016), assessment of the effectiveness and practical feasibility of glass solar chimney walls by open frame for Thailand by Ratanachotinun and Pairojn (2017), the development of paint with silica aerogel for thermal insulation and energy saving by Ratanachotinun and Pairojn (2021), a feasibility study of glass solar chimney wall for tropical area, case study: Bangkok, Thailand by Ratanachotinun and Pairojn (2014) and technical and economical assessment of energy-saving roof and wall construction in Thailand by Ratanachotinun et al. (2016).

Research related to the use of plastic bottles in construction and building material development such as the study of hollow aerated bricks for reducing heat transfer into buildings by Ratanachotinun and Pairojn (2020) is a study of lightweight aerated bricks with hollow round holes in the center of the bricks to help increase thermal insulation resulting in energy saving building. Modification of plastic drinking water bottle waste material for use in the design of the parking lot light filter by Tantiyaswasdikul (2010) has brought plastic containers of drinking water bottle waste to be designed as a light filter in the outdoor parking area. The study on the ratio of polypropylene plastics in aerated bricks to compressive strength and thermal conductivity by Nitisuwanraksa (2016) was to analyze the possibility of replacing sand with polypropylene plastic in the production of aerated bricks. Analysis of rubber tiles mixed with industrial waste plastic waste by Deepunya and Suveero (2015) is the development of rubber tiles mixed with ethylene vinyl acetate waste from industrial plants. A study of short used plastic strands mixed in concrete by using PET and HDPE plastics to reinforce concrete for increased flexural strength and reduced cracking. The study of short used plastic strands mixed in concrete by using PET and HDPE plastics to reinforce concrete to increase flexural strength and reduce cracking by Suriyawichitseranee et al. (2000) found that plastic strand reinforcement provided compressive strength and modulus values. Flexibility decreases as the amount of plastic filament increases, but increases the flexural strength of concrete. The study of behavior and load analysis of reinforced concrete beams mixed with PET by Mohammed (2017) were used as small-sized PET plastics to replace fine aggregate or sand in the concrete mix. And others were experimental study on the effect of wastewater and waste slurry of mixing plant on mechanical properties and microstructure of concrete by Chen et al. (2022), and performance of waste polyethylene modified bituminous paving mixes containing reclaimed asphalt pavement and recycled concrete aggregate by Purohit et al. (2022). Past researches have shown that there are still variables that are not considered coarse aggregate or stone which is a component of concrete with a material cost of about 15 USD per cubic meter or 20% of the total cost of concrete. Therefore, to reduce the cost of concrete, the coarse aggregate volume should be reduced by replacing it with used plastic bottles and still have the compressive strength suitable for the load in civil engineering. Disposing of plastic bottles by mixing them in construction concrete can help reduce the amount of plastic water bottle waste and waste disposal costs. Eco-concrete mixed with used plastic bottles (ECP) is a low-cost concrete and alternatively eliminates waste of plastic water bottle in community areas, hence the origin of this research.

This research was to develop the efficiency of eco-concrete mixed with used plastic bottles to replace all of the coarse aggregate (ECPA) and eco-concrete mixed with used plastic bottles to replace some of the coarse aggregate (ECPS) for construction, the load-bearing performance testing of concrete with the various proportion of used plastic bottles to replace all and some of the coarse aggregate suitable for construction, cost savings and environmental impact of ECP and construction testing by ECPA and ECPS in community areas of Thailand.

2. MATERIALS AND METHODS

This research has the following steps: preparation of materials and instruments for testing, testing for specific gravity and water absorption of aggregates, concrete mix design for testing, preparation of concrete samples and compressive strength testing and analysis of data and conclusions.

2.1 Preparation of materials and instruments for testing

This experiment used portland cement type 1, aggregates which are divided into coarse aggregates or rock and fine aggregates or sand and water. Plastic water bottles which made from polyethylene terephthalate (PET) that are commonly used in Thailand. For shredding plastic bottles for mixing into concrete, the sample uses a clear plastic drinking water bottle cut into a square with a flat edge to a size of 1 × 1 cm, the proportion of the PET that replaced the all coarse aggregate was 5, 10, 15 and 17 percent by cement weight and the PET mixture that replaced the some coarse aggregate was 5, 10, 15, 20, 25 and 30 percent by coarse aggregate weight. The important instruments for testing the compressive strength of concrete samples are the cubic concrete sample formwork 15 × 15 × 15 cm and the compressive strength testing machine as shown in Fig. 1.

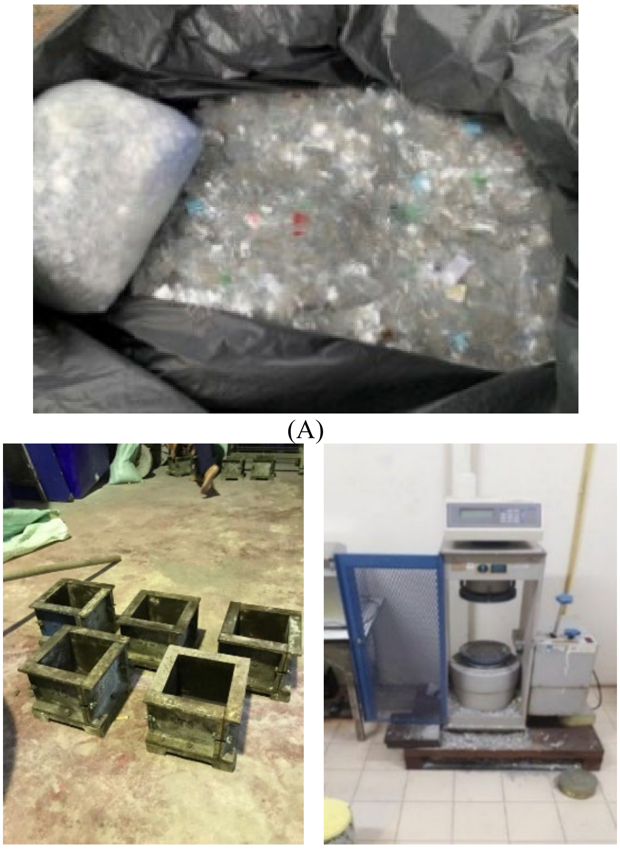
2.2 Testing for Specific Gravity, Water Absorption of Aggregates and Others

The testing for coarse aggregate and fine aggregate determines the total specific gravity, the sieve analysis, fineness modulus, apparent specific gravity and water absorption. The testing for coarse aggregate are based on ASTM C127 standard test method for density, relative density (specific gravity) and absorption Aggregate. Determination of specific gravity and water absorption of fine aggregate materials, the test standards are based on ASTM C128 standard test method for density, relative

International Journal of Applied Science and Engineering

Ratanachotinun, International Journal of Applied Science and Engineering, 20(1), 2022193

density (specific gravity), and absorption of fine aggregate.



(A)

(B) (C)

Fig.1. Plastics and testing machines for research (A) Sample of used plastic water bottles cut to size 1 × 1 cm (B) Cube-shaped concrete samples (C) Compressive strength testing machine

2.3 Concrete Mix Design for Testing

Mixture ratio for compressive strength test of ECP is based on Rochanavibhata (2017) by calculating the concrete mix design according to the ACI standard. This research uses typical concrete for comparison with a compressive strength of 240 kg/cm^2 by determining the volume of 1:2:4 using 1 part of cement, 2 parts of sand and 4 parts of rock. Therefore, the design calculation of 1 cubic meter of concrete mix can yield the prototype ratio for testing, which is cement equal to 300 kg, sand equal to 624 kg, rock is equal to 1,296 kg and water equal to 180 kg. PET mixing to replace coarse aggregate. From the test of mixing plastic bottles in concrete by substituting all coarse aggregate in the first step research by trial and error, it was found that the ratio of plastic bottles to coarse aggregate or rock was the ratio as 1:13 by weight, so concrete can be mixed and workability. Fig. 2. is an improper PET mix ratio test, resulting in the concrete being unable to soundness and workability. Mix design for the ECPA test is shown in Table 1. And this test is not using mixed rock in the concrete, using plastic instead, so the amount of cement and sand may be greater than the design range of ecological concrete mix design in order to suitable compressive strength and workability. For this reason, the amount of cement and sand for ECPA are invalid according to the design range of ecological concrete mix design. The mixing ratio of ECPA sand and cement may be inaccurate with the volume of both greater than 1 cubic metre because this experiment requires modification of the mix that does not refer to the design principles of normal concrete mixture and also allows the concrete to obtain compressive strength. The proportion of replacing rock with plastic comes from the experiment in Table 1. The density of plastic is much less than that of rock, so the replacement ratio must be determined experimentally, and the amount of plastic and rock is very different. Based on the replacement ratio of plastic bottles and coarse aggregate (1:13), the volume of plastic bottles used in concrete for partial replacement of coarse aggregate was calculated as shown in the design of the ECPS mixture for testing in Table 2.

Fig. 2. Concrete mixed with plastic bottles as an unsuitable substitute for coarse aggregate

Table 1. The total mass mixture of ECPA for 1 m^3

Cement (kg)	Sand (kg)	Rock (kg)	Water (kg)	PET (% by Cement weight)	PET (kg)
300	624	1296	180	0	0.000
1322	2714	0	793	5	66
1016	2082	0	610	10	102
638	1310	0	383	15	95
549	1196	0	329	17	93

Table 2. The total mass mixture of ECPS for 1 m^3

Cement (kg)	Sand (kg)	Rock (kg)	Water (kg)	PET (% by Rock weight)	PET (kg)
300	624	1296	180	0	0.000
300	624	1231	180	5	4.925
300	624	1166	180	10	9.850
300	624	1102	180	15	14.774
300	624	1037	180	20	19.699
300	624	972	180	25	24.624
300	624	907	180	30	29.549

2.4 Preparation of Concrete Samples and Compressive Strength Testing

Cube concrete samples used for compressive strength test per curing period of 7, 14 and 28 days are all included in each of the mixed proportions equal to 9 samples. The proportion of plastic mixtures to replace the all coarse aggregates consisted of 4 sample sets. The proportion of plastic mixture to replace some of the coarse aggregate was 6 sample sets. And typical concrete for comparison was 1 sample set. Therefore, the total number of concrete samples for testing is 99 samples. There are weighing of concrete samples for density and compressive strength testing is carried out in accordance with ASTM C 39. Compressive strength test results are presented in tables and charts comparing typical concrete with ECPA and ECPS.

2.5 Analysis of Data and Conclusions

Analysis of the data compares the compressive strength of ECP at different plastic proportion. Assessing the suitability of the compressive strength for the type of construction mathematical analysis of the relationship between the compressive strength of concrete and the plastic mix ratio. Cost analysis and environmental impact of ECP. And the conclusion of the research

3. RESULTS AND DISCUSSION

Analysis of research data is divided into properties of materials used for testing, compressive strength test, damage characteristics of ECP, cost and environmental impact analysis of ECP and the use of ECP for the actual construction of community areas in Thailand.

3.1 Properties of Materials Used for Testing

The materials used for the construction of concrete samples for their basic properties can be shown as follows: portland cement type 1, fine aggregate or sand used, has an average of specific gravity of 2.56 and fineness modulus of 4.212 The average of apparent specific gravity was 2.68 and the average of water absorption rate was 1.64%. The coarse aggregate or rock used had the average of specific gravity of 2.74 and fineness modulus of 2.473. The average of apparent specific gravity was 2.77 and the average of water absorption rate was 0.43%. Plastic water bottles for the experiment had an average density of 1350 kg/m^3 and the plastic water bottles were shredded to a size of approximately 1 × 1 cm. Table 3 and 4 showed the sieve analysis for coarse aggregate and fine aggregate.

3.2 Compressive Strength Test

The results of testing for the compressive strength of typical concrete, ECPA and ECPS are shown in Tables 5 to 6 and Figs. 3 to 5.

From Tables 5-6 and Figs. 3-4, it was found that ECPA gave almost all PET proportions of compressive strength less than 200 kg/cm^2. only 5% gave the average compressive strength greater than 200 kg/cm^2. But the concrete mix ratio requires an increase in the amount of cement and sand, resulting in higher concrete costs and the design of concrete mix is still uncertain.

Table 3. Sieve analysis for fine aggregate

Sieve Number	Mass of sieve (g)	Mass of sieve + sand (g)	Weight retained (g)	% Weight retained	Cumulative % retained	Cumulative % passing
4	1,597	1,598.30	1.30	0.26	0.26	99.74
10	1,408.80	1,476.30	67.50	13.41	13.67	86.33
20	1,249.50	1,394.30	144.80	28.78	42.45	57.55
50	1,095.20	1,287.40	192.20	38.20	80.64	19.36
80	1,055.30	1,109.80	54.50	10.83	91.47	8.53
100	956	969.6	13.60	2.70	94.18	5.82
200	923.2	945	21.80	4.33	98.51	1.49
Pan	1,049.10	1,056.60	7.50	1.49	100.00	0
Total	9,334.10	9,837.30	503.2	100		

Table 4. Sieve analysis for coarse aggregate

Sieve Size (in.)	Mass of sieve (g)	Mass of sieve + rock (g)	Weight retained (g)	% Weight retained	Cumulative % retained	Cumulative % passing
1	1708.9	1709.1	0.2	0.0192	0.0192	99.9808
0.75	1623.1	1736.8	113.7	10.901	10.920	89.080
0.5	1692.2	2201.9	509.7	48.869	59.789	40.211
0.375	1722.2	1918.5	196.3	18.821	78.610	21.390
0.187	1584.5	1786	201.5	19.319	97.929	2.071
Pan	1048.3	1069.9	21.6	2.071	100.000	0
Total	9379.2	10422.2	1043	100.000		

Therefore, ECPA is not suitable for infrastructure construction, but less than 200 kg/cm^2 can be used. The appropriate ECPS for construction is the proportion of PET at the level of 10% by weight of coarse aggregate, which has a compressive strength of not less than 200 kg/cm^2, which is considered an acceptable value in the design of building structures. When the proportion of PET in concrete is greater than 10% by weight of coarse aggregate, it has a compressive strength of less than 200 kg/cm^2, which can be used for designing in low-load construction like ECPA, such as walkways, re-pavement and lean concrete etc. An analysis of the relationship between the compressive strength of concrete and the PET ratio for ECPA, due to the unstable mix ratio and low compressive strength, is not suitable for mathematical analysis. For ECPS, the analysis results can be shown in Fig. 5. It was found that there was a mathematical relationship as shown in Equation (1). and analyzed the most proportion of PET in the concrete, resulting in the concrete having a compressive strength of not less than 200 kg/cm^2 which is 11.46% of the coarse aggregate weight.

$$y = -0.139x^2 - 1.3381x + 233.63 \quad (1)$$

y = Compressive strength of concrete (kg/cm^2)
x = The proportion of PET by coarse aggregate (%)
R^2 = Coefficient of Determination (0.9739 nearly 1.00)

Table 5. The average of ECPA compressive strength in each proportion according to the curing age of 7, 14 and 28 days

Curing (day)	PET (%)	Density (kg/m^3)	Peak Load (kg)	Compressive strength (kg/cm^2)	Slump (cm)
	0	2370.08	44603	198.26	10.5
	5	2077.96	44870	199.37	11
7	10	2049.36	31073	138.1	11.5
	15	2170.34	30323	134.93	12
	17	2167.13	21397	95.1	11.5
	0	2394.19	48647	216.2	10.5
	5	2125.26	45307	201.33	11
14	10	1980.13	32117	144.97	11.5
	15	2026.38	32204	143.13	12
	17	2097.53	23820	105.87	11.5
	0	2329.57	52988	235.5	10.5
	5	2159.24	50637	225.1	11
28	10	1985.02	33753	153.33	11.5
	15	2134.43	33943	150.86	12
	17	2056.48	26378	117.21	11.5

Table 6. The average of ECPS compressive strength in each proportion according to the curing age of 7, 14 and 28 days

Curing (day)	PET (%)	Density (kg/m^3)	Peak Load (kg)	Compressive strength (kg/cm^2)	Slump (cm)
	0	2370.08	44603	198.26	10.5
	5	2366.79	44687	198.6	12.5
	10	2375.83	35187	156.37	11
7	15	2159.1	30533	135.73	12
	20	2348.47	32203	143.13	9
	25	2447.55	24750	110	8.8
	30	2137.27	10287	45.71	5
	0	2394.19	48647	216.2	10.5
	5	2421.08	48363	214.93	12.5
	10	2398.58	45203	200.9	11
14	15	2353.49	31790	141.27	12
	20	2388.71	34007	151.13	9
	25	2429.52	26363	117.17	8.8
	30	2187.8	13487	59.94	5
	0	2329.57	52988	235.5	10.5
	5	2416.82	49980	222.13	12.5
	10	2401.22	47317	211.03	11
28	15	2413.38	36933	164.13	12
	20	2416.13	36703	163.13	9
	25	2440.23	27208	120.92	8.8
	30	2133.05	13933	61.93	5

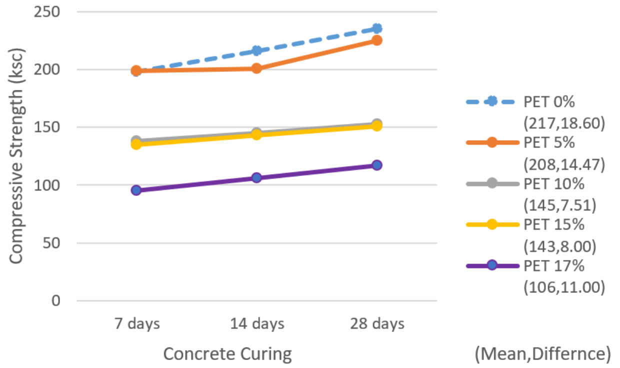


Fig. 3. Comparison of ECPA compressive strength in each proportion with typical concrete at the curing age of 7, 14 and 28 days

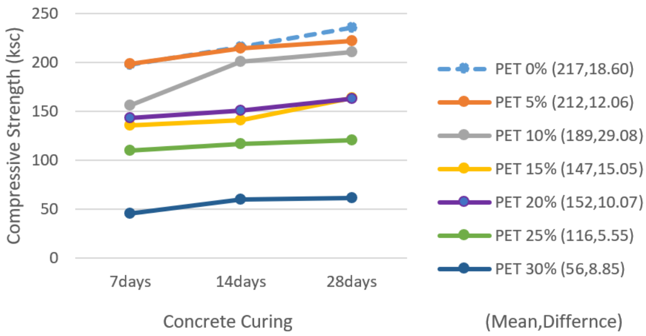


Fig. 4. Comparison of ECPS compressive strength in each proportion with typical concrete at the curing age of 7, 14 and 28 days

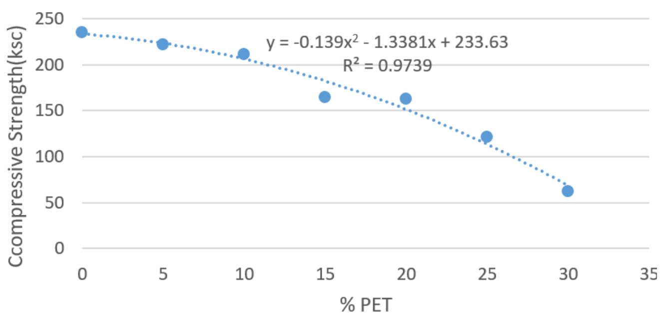
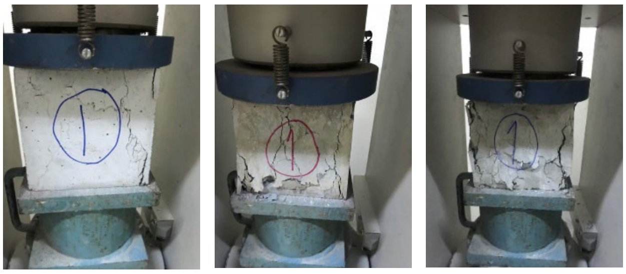


Fig. 5. Mathematical analysis of the relationship between the compressive strength of concrete and the mixing proportion of PET to replace the some coarse aggregate

3.3 Damage Characteristics of ECP

The damage characteristics of the compressive strength test are compared between typical concrete and ECPA, ECPS as shown in Fig. 6. The deformation of a typical concrete sample is characterized by large fragments. For ECPA and ECPS, it will be broken into smaller fragments. There is more damage than typical concrete especially ECPA is the most damaged. The increased proportion of PET substituted for coarse aggregate will increase the damage characteristics of the concrete sample and result in a decrease in the compressive strength of the concrete.



Typical concrete ECPS ECPA

Fig. 6. Comparison of damage of concrete samples between typical concrete, ECPS and ECPA

3.4 Cost and Environmental Impact Analysis of ECP

From Peri (2012) explains the average cost of plastic bottle or PET waste disposal is about 0.15 USD/kg. Therefore, the cost reduction of PET disposal can be calculated. The calculation of the cost of concrete takes into account the cost of materials only, does not include labor costs and is shown in Tables 7-8. For the ECPA analysis, it was found that concrete mixed with the PET ratio of 5% per cement weight which has the highest load-bearing capacity at 225 kg/cm^2, but has the highest cost at 122.73 USD/m^3 due to the amount of cement and sand that must be added for the soundness and workability, affecting the cost of concrete 98.7 percent more than typical concrete. And it is likely that the cost of concrete will decrease as the proportion of PET mixed increases. For ECPS, it is found that concrete costs tend to decrease with the proportion of PET mixed increasing. For ECPS applications, considering the compressive strength tested, PET-mixed concrete should be selected in the ratio of 5% and 10% of the coarse aggregate weight. The average compressive strength was about 224.5 kg/cm^2 and 217.4 kg/cm^2 respectively with the compressive strength similar to that of typical concrete. And the cost of ECPS is approximately 60.27 and 58.73 USD/m^3 respectively or the cost is reduced from typical concrete by 2.4 to 5 percent. An environmental impact analysis based on the Japan International Cooperation Agency (2010) together with the Bangkok Metropolitan Administration (BMA) explains that reducing 1 kg of plastic waste will reduce CO_2 gas about 0.3 kg. The results of CO_2 emissions analysis from plastic waste disposal show that ECPA can reduce CO_2 emissions on average 20-30 kg/m^3. And ECPS can reduce CO_2 gas by an average of 1.5-9 kg/m^3. According to the trend of construction materials industry in Thailand by Bank of Ayudhya Public Company Limited (2021) explains the consumption of concrete for Thailand construction in 2020, the consumption of concrete for residential construction is approximately 10,000,000 m^3/year. The switching to ECPS for construction in community areas is defined as a minimum of 1% of the total concrete consumption in Thailand's residential construction throughout the year which is equal to 100,000 m^3/year and the reducing of CO_2 emissions from incineration of used plastic water bottles at least 147,300 kg/year. Supporting more applications will be able to further reduce CO_2 as shown in the analysis results in Table 9. The ECPA does not analyze the environmental impact due to the uncertain mix ratio, compressive strength less than 200 kg/cm^2 and the high cost of concrete therefore cannot be used for structural construction. Therefore, ECP can be applied to construction work in Thailand community areas by selecting the appropriate load-bearing capacity and also reducing the problem of plastic water bottle disposal that affects environmental pollution.

3.5 The Use of ECP for the Actual Construction of Community Areas in Thailand

The use of ECPA to be tested in real construction works by adjusting the road surface within Chandrakasem Rajabhat University which supports light traffic volume and low vehicle weight. The improvement of road pavement will be poured concrete over the former road surface that has been eroded with a thickness of about 3 centimeters of the newly poured pavement and a width of about 1.5 meters and a length of 10 meters. Therefore, a mixture of 15 percent PET ratio is selected. The compression strength of the mixed proportion can also support the traffic volume in the area as shown in Fig. 7.

The practical application of ECPS in construction by constructing the multi-purpose courtyard floor of Minburi Upatham Community, Minburi District, Bangkok, Thailand. The construction area is approximately a thickness of about 7 centimeters and a width of about 7 meters and a length of 8 meters. The proportion of plastic used in construction is 10%. The construction is shown in Fig. 8.

4. CONCLUSION

Compressive strength tests of ECPA and ECPS showed that ECPA had an average compressive strength of less than 200 kg/cm^2 and decreased as the proportion of PET increased compared to typical concrete.

Table 7. Comparison between the proportions of ECPA per 1 cubic meter, average compressive strength and concrete cost

PET (%)	0	5	10	15	17
Cement (kg)	300	1322	1016	638	549
Sand (kg)	624	2714	2082	1310	1196
Rock (kg)	1296	0	0	0	0
PET (kg)	0	66	102	95	93
Strength (kg/cm^2)	235.5	225.1	153.33	150.86	117.21
Initial average cost (USD/m^3)	61.77	132.73	102.12	64.12	55.76
Average cost of plastic disposal (USD)	0	10	15.45	14.39	14.09
Final average cost (USD/m^3)	61.77	122.73	86.67	49.73	41.67
Amount of CO_2 from plastic waste disposal (kg)	0	19.8	30.6	28.5	27.9

Table 8. Comparison between the proportions of ECPS per 1 cubic meter, average compressive strength and cost

PET (%)	0	5	10	15	20	25	30
Cement (kg)	300	300	300	300	300	300	300
Sand (kg)	624	624	624	624	624	624	624
Rock (kg)	1296	1228	1163	1098	1033	969.2	904.7
PET (kg)	0	4.91	9.812	14.73	19.64	25	29
Strength (kg/cm^2)	230.85	224.5	217.4	172.5	169.48	136.28	68.5
Initial average cost (USD/m^3)	61.77	61.03	60.24	59.48	58.73	58.00	57.24
Average cost of plastic disposal (USD)	0	0.76	1.52	2.24	2.97	3.79	4.39
Final average cost (USD/m^3)	61.77	60.27	58.73	57.24	55.76	54.18	52.85
Amount of CO_2 from plastic waste disposal (kg)	0	1.473	2.944	4.419	5.892	7.500	8.700

Table 9. Analysis of the amount of CO_2 that can be reduced by using ECPS in Thailand

Proportion of using ECPS for construction in the community (%)	Mixing proportion of PET in ECPS (% by coarse aggregate) / Amount of CO_2 reducing (kg/year)					
	5	10	15	20	25	30
1	147,300	294,400	441,900	589,200	750,000	870,000
5	736,500	1,472,000	2,209,500	2,946,000	3,750,000	4,350,000
10	1,473,000	2,944,000	4,419,000	5,892,000	7,500,000	8,700,000
15	2,209,500	4,416,000	6,628,500	8,838,000	11,250,000	13,050,000
20	2,946,000	5,888,000	8,838,000	11,784,000	15,000,000	17,400,000
25	3,682,500	7,360,000	11,047,500	14,730,000	18,750,000	21,750,000
30	4,419,000	8,832,000	13,257,000	17,676,000	22,500,000	26,100,000

Fig. 7. The resurface of the pavement around the roads inside Chandrakasem Rajabhat University by ECPA

Fig. 8. Construction of a multi-purpose concrete courtyard floor of Minburi Upatham Community, Minburi District, Bangkok, Thailand by ECPS

The mixing ratio of PET in the concrete with the highest compressive strength was 5% by weight of cement and the average of maximum compressive strength was 225 kg/cm^2. The mixing and forming ability of concrete depends on the proportion of PET mixed in the concrete should not exceed 15% by weight of cement, the proportion of PET greater than 15% will affect the concrete not workability and unable to soundness. Using used plastic water bottles to replace all coarse aggregate in concrete, the ratio between the used plastic and stone was analyzed. From the experiment by trial and error, it was found that the proportion of plastic that is suitable for replacing coarse aggregate for mixing and still able to be soundness and workability has a ratio of plastic to stone equal to 1:13 by weight. ECPA is not suitable for structural construction requiring compressive strength greater than 200 kg/cm^2. ECPS with more PET proportion will result in lower compressive strength compared to typical concrete. The ideal proportion of PET partially substituted for coarse aggregate is level not more than 10% of coarse aggregate weight. The compressive strength of the sample concrete was 217.4 kg/cm^2 which is not less than 200 kg/cm^2 and is suitable for the design of building structures for loading. The mixture of PET in concrete greater than 10% of the coarse aggregate weight has a compressive strength of less than 200 kg/cm^2.

The mathematical relationship of ECPS between the compressive strength of concrete and the PET mix ratio was found that the highest proportion of PET mixture capable of yielding compressive strength not less than 200 kg/cm^2 was 11.46%. So practice, PET should be mixed to replace coarse aggregate not more than 10% in order to have the ability to design the structure. However, for ECPA, the relationship cannot be analyzed mathematically due to the uncertainty of the mixture and the compressive strength significantly less than 200 kg/cm^2. The damage characteristics due to compressive strength tests shows that typical concrete will have the appearance of breaking into large fragments, for the ECP samples are small fragments but still has a cubic shaped adhesion. And the increased proportion of PET substituted for coarse aggregate increased the damage characteristics of the concrete samples which were proportional to the decrease in the compressive strength of the concrete. The mixing of PET as a substitute for some coarse aggregate is that the concrete density is reduced by about 2%-3% from the density of normal concrete, indicating that the dead load will be reduced, making the overall design of the building structure smaller and saving construction costs. The suitability of construction between ECPA and ECPS when considering the compressive strength found that ECPS is stronger and more stable in construction. The cost analysis of ECP in the ECPA section found that the mixing ratio of PET is equal to 5% of the cement weight with the highest load-bearing value of 225 kg/cm^2, but the highest cost is 122.73 USD/m^3 or approximately 98.7% more than the typical concrete cost due to the amount of cement and sand, mixing is required for soundness and workability and the mix design is uncertain. The overall cost of ECPA is very high. The ECPS analysis found that the concrete cost tends to decrease in proportion to the increased PET mix.

For ECPS applications, considering the compressive strength tested, PET mixtures should be selected not more than 10% of the coarse aggregate weight with an average compressive strength of 217.4 kg/cm^2 and the cost of ECPS is 58.73 USD/m^3 which is about 5% reduction from the cost of typical concrete. The higher the PET mix ratio in ECP, the compressive strength is less than 200 kg/cm^2 which is too low for the design of structures that require heavy loads but can also be used in low load construction such as walkways, re-pavement and lean concrete etc. An analysis of the environmental impact of CO_2 reduction from plastic waste disposal revealed that ECPA and ECPS can reduce CO_2 by an average of 20-30 and 1.5-9 kg per 1 cubic meter of concrete respectively. The result of promoting for the construction of ECP, especially ECPS, will be able to reduce the amount of CO_2 from the disposal of plastic water bottles at least 147,300 kg/year. And supporting for more applications will be able to reduce the more amount of CO_2. In terms of cost and CO_2 reduction, ECP have been shown to be effective if they are widely used, especially in community areas. Construction using ECP has conducted a trial of real construction work in community areas in Thailand, choosing the type of construction that is suitable for compressive strength and also reduces the problem of plastic bottle waste disposal that affects environmental pollution. Future research could use other waste materials mixed with plastics in concrete such as EPS foam to replace fine aggregate, which could reduce EPS foam waste and the cost of fine aggregate.

ACKNOWLEDGEMENTS

This research was financial supported by Chandrakasem Rajabhat University Research Grant.

REFERENCE

Bank of Ayudhya Public Company Limited., 2021. Industry Outlook 2021-2023: Construction Materials. Bank of Ayudhya Public Company Limited, Thailand. Retrieved 2021-10-01 from www.krungsri.com/th/research/industry/industry-outlook/Construction-Construction-Materials/Construction-Materials/IO/io-construction-materials-21

Chen, X., Wu, J., Ning, Y., Zhang, W. 2022. Experimental study on the effect of wastewater and waste slurry of mixing plant on mechanical properties and microstructure of concrete. Journal of Building Engineering, 52, 1–13.

Deepunya., W., Suveero, K., 2015. “Para-rubber Floor Tiles Mixed with Plastic Wastes from the Factories”. Report Budget research subsidies annual Revenue Budget 2015 Bangkok. Rajamangala University of Technology Phra Nakhon. Thailand.

Japan International Cooperation Agency. 2010. Cool down our beloved earth: A handbook on global warming. Japan International Cooperation Agency and The Bangkok Metropolitan Administration. Retrieved 2021-10-01 from https://www.jica.go.jp/thailand/english/office/topics/c8h0vm0000bm5965-att/events100929_01.pdf.

Mohammed, A.A. 2017. Flexural behavior and analysis of reinforced concrete beams made of recycled PET waste concrete. Construction and Building Materials, 155, 593–604.

Nitisuwanraksa, N. 2016. Effects of polypropylene plastic ratio in autoclaved aerated concrete on compressive strength and thermal conductivity. Kasem Bundit Engineering Journal, 6, 174–181.

Peri, G., Travrso, M., Finkbeiner, M., Rizzo, G., 2012. The cost of green roofs disposal in a life cycle perspective: Covering the gap. Energy, 48, 406–414.

Purohit, S., Panda, M., Das, A.K., 2022. Performance of waste polyethylene modified bituminous paving mixes containing reclaimed asphalt pavement and recycled concrete aggregate. Construction and Building Materials, 348, 1–16.

Ratanachotinun, J., Pairojn, P. 2021. The development of paint with silica aerogel for thermal insulation and energy saving. International Energy Journal, 21, 437–446.

Ratanachotinun, J., Pairojn, P. 2020. Assessment of the feasibility of autoclaved aerated concrete with perforation in Thailand. Journal of Applied Science and Engineering, 23, 249–259.

Ratanachotinun, J., Kasayapanand, N., Hiunlabh, J., Visitsak, S., Teekasap, S., Khedari, J. 2016. A design and assessment of solar chimney of bioclimatic house wall and roof for construction in the housing market of Thailand. Building Services Engineering Research and Technology, 37, 694–709.

Ratanachotinun, J., Pairojn, P. 2017. Assessment of the effectiveness and practical feasibility of glass solar chimney walls by open frame for Thailand. Building Services Engineering Research and Technology, 38, 51–162.

Ratanachotinun, J., Pairojn, P. 2014. A feasibility study of glass solar chimney wall for tropical area, Case study: Bangkok, Thailand. International Energy Journal, 14, 95–106.

Ratanachotinun, J., Kasayapanand, N., Hiunlabh, J., Visitsak, S., Teekasap, S., Khedari, J. 2016. Technical and economical assessment of energy-saving roof and wall construction in Thailand. Journal of the Chinese Institute of Engineers, 39, 1–11.

Rochanavibhata, U. 2017. Concrete laboratory. Civil Engineering Department, Faculty of Engineering, King Mongkut's University of Technology North Bangkok. KMUTNB Textbook Publishing Center. Thailand.

Suriyawichitseranee, A., Seangatith, S., Apichatvullop, A. 2000. Inverstigation of the use of recycled short plastic wires in concrete. In Proceedings of the 11th National Convention on Civil Engineering. Phuket, Thailand, 1–6.

Tantiyaswasdikul, K. 2010. Transformation of waste plastic bottles into covered parking. Journal of Architectural/Planning Research and Studies, 7, 159–172.