



CO₂-emission assessment of the concrete added crushed PET bottles waste

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Abstract

PET-bottles generate a significant amount of waste disposal which may affect to people health and environment according to with UNEP report. The study of PET waste as a component in concrete may be the worth waste management approach for both plastic waste reduction and construction material development. The paper presents the compressive strength of specific samples by varying three levels of percentage 0%, 3% and 6% for crushed PET waste bottle waste added in concrete and propose CO₂-emission assessment model of these mixes of concrete material. All test cube samples are 28 days curing aging. Accordingly, the test results were compared to conventional concrete and waste PET mixed concrete and checked by linear regression analysis to find the correlation between the compressive strength and the percentage of PET as well as the CO₂ emission quantity of concrete mixes. This study will be a helpful part to encourage sustainable development by PET bottle waste reduction and CO₂ emission reduction concept as well as the development guide of alternative concrete material.

Keywords: conventional concrete (CC), waste PET mixed concrete (WPMC), CO₂ emission (CO₂e)

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1. Introduction

Waste pollution is one of the severe environmental issues. Waste recycling rate increment is needed an approach to reduce excessive waste which over treatment capacity. Plastic waste is non-biodegradable waste which can be remained over 100 years in an environment thus more increasing of plastic waste recycling by using as an additive component in construction material can be a part to encourage the recycle plastic waste increasing principal. The use of plastic waste by addition in the concrete mixture is the benefit in both construction material development and plastic waste pollution mitigation. Hence, there are many studies on the properties of plastic waste mixed with concrete. The comparative study of the compressive strength by using manual cut and shredded PE plastic bag 0%-1.2% by volume mixed in concrete and found that the compressive strength reduced 30% at 0.6% of plastic and dropped up to 50% when 1.2% of plastic was added to concrete by volume of concrete [1].

The premixed mortar blended with recycling plastic compressive strength was lower than normal premixed mortar which had no recycle plastic material mixed in mortar mixture, and the compressive strength was decreased when the percentage of recycling plastic in the mortar was increased [2].

PET is the abbreviation of Polyethylene terephthalate, It is the plastic that is an excellent water barrier and safe for use as drinking water bottle and beverage container. The large amount of PET bottle was consumed as well as generated PET waste.

The cube compressive strength of concrete contained shredded PET was higher than conventional concrete. Moreover, the suggested optimal percentage of cut shred form PET added in the concrete was 0.25% by volume of concrete [3]. Likewise, there was noticed that the compressive strength increased up to 2% replacement of the fine aggregate with PET bottle fibers [4]. Although material performance studies were reported the study on CO₂-emission assessment of PET bottle waste mixed in the concrete have been insufficiently presented in Thailand.

This study focuses on the compressive strength of crushed PET plastic mixed in concrete. By which performs cube sample test compared to conventional concrete in according with material testing standard and propose CO₂-emission assessment by CO₂e factors, From reference [5] stated that Carbon dioxide equivalent (CO₂e) is a term described the different greenhouse gases in a common unit. The CO₂e factor of each constituent in concrete [6] will be used to evaluate CO₂ emission of the specific mixes. The concrete mixed with PET waste will be the alternative approach to reduce PET bottle effect [7].

2. Materials and methods

2.1 Materials

1) Portland Cement Type 1: Dry cement which is used for structural concrete. This material is available in the local market and has been produced conforms to the specification of TIS 15-2532 [8].

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2) PET-Bottle: The regularly PET (Polyethylene Terephthalate) which is post-consumer plastic. PET density is between 1.30 g/cm³. The used PET-bottle was formed by crushing machine as shown in Figure 1.

3) Aggregates: Fine aggregate (Sand) and Coarse aggregate (crushed stone) were used for specimen preparation. The specific gravity of the aggregate for a concrete mixture is shown in Table 1.

4) Water: The water quality which used for concrete mixture complied with ASTM C1602 [9].

2.2. Mix Design and Method

1) Mix Design of the concrete

Conventional Concrete(CC) is the ordinary Portland cement concrete (0% of PET mixed), and Waste Plastic Mix Concrete (WPMC) is the concrete added the plastic waste by the percentage of the cement weight and mixed design calculation of concrete followed the given guideline provided by E.I.T. Standard1014-46 [10]. The PET waste plastic used in this studying is PET in percentage (1%, 2%, 3%, 4% and 6% PET mix) of cement weight. The aggregate and water quantities were shown in Table 2.

2) Methods

The methodology of the study is based on experimental research, and an operation can be shown in Figure 2.

2.3 Sample preparation

Concrete samples were prepared in three cube samples for each mix. Doing CC and WPMC samples by varying the percentage of PET fiber in the concrete mixture. The PET plastic used proportion by 0%, 1%, 2%, 3%, 4% and 6% of the used quantity of cement weight added to the mixes of dry cement and aggregates. Filled the water and mixed by hand tool mixing until become concrete paste mixture. Placed the dough into the clean molds to perform the cube samples (size 150 mm. width x 150 mm. length x 150 mm. depth) as shown in Figure 3 and remove the molds after setting time of samples in the mold 24 hours. All were marked the mixed code and cast date as shown in Figure 4. Furthermore, cure the samples in water basin until completion of the age 28 days.



Figure 1 Crushed form PET



Figure 2 Operation research program

Table 1 Aggregate specific gravity

Aggregate Type	Specific Gravity (g/cm ³)	Absorption (%)
Fine Aggregate	2.60	<3.5
Coarse Aggregate	2.70	<3.5

Table 2 Mix Design of Conventional Concrete (CC) and Waste PET mixed concrete (WPMC)

Mix	Cement (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Water (kg/m ³)	PET (kg/m ³)	Water/Cement Ratio
CC (0% PET)	296.00	790.00	1086.00	200.00	0.00	0.68
WPMC (1% PET)	296.00	790.00	1086.00	200.00	2.96	0.68
WPMC (2% PET)	296.00	790.00	1086.00	200.00	5.92	0.68
WPMC (3% PET)	296.00	790.00	1086.00	200.00	8.88	0.68
WPMC (4% PET)	296.00	790.00	1086.00	200.00	11.84	0.68
WPMC (6% PET)	296.00	790.00	1086.00	200.00	17.76	0.68



Figure 3 Molds for cube sample



Figure 4 Removal of molds and marking samples



Figure 5 Compressive strength test machine

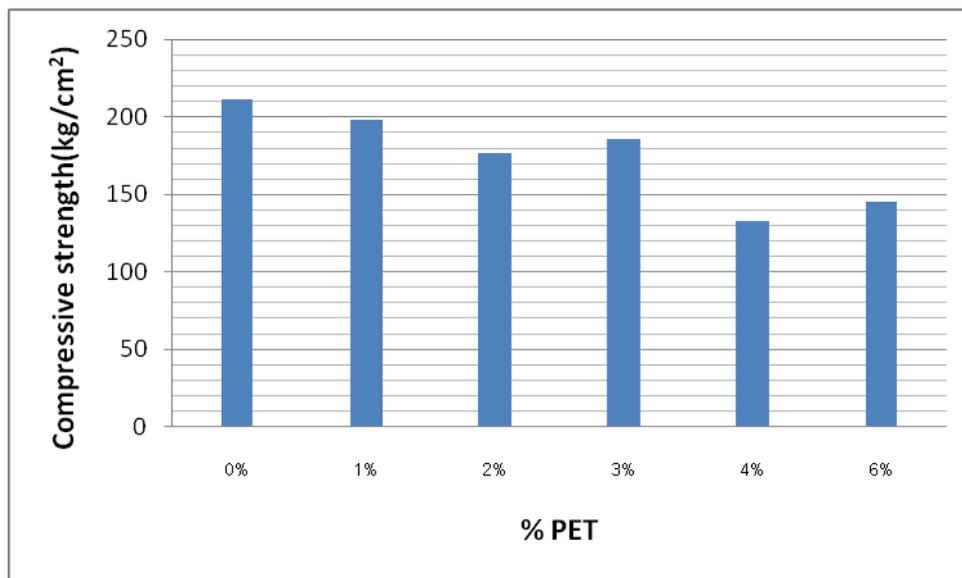


Figure 6 Compressive strength of CC (0%) and WPMC (1%, 2%, 3%, 4% and 6%) at 28 days age

2.4 Compressive strength test

The sample test is proceeded to follow test standard [11]. The testing machine set is shown in Figure 5.

3. Results and discussion

The three cube samples of each mix at 28 days curing time-tested including control samples which are conventional concrete (0% PET). The test is collected and analyzed as following results.

3.1 Compressive Strength Test result

The compressive strength of specimens was obtained as following results, The 28 days average

conventional concrete (CC) compressive strength was higher than crushed waste PET mixed concrete (WPMC) as shown in Figure 6.

The compressive strength of concrete which water / cement ratio equals to 0.68, It strength trend is low because of high volume of water content and low cement content in concrete mixture caused the strength in low level.

3.2 The correlation between the compressive strength and % PET content

The compressive strength of cube samples for 0%, 1%, 2%, 3%, 4% and 6% of crushed waste PET can be represented by predictive equation model

which analyzed by simple regression analysis as shown in Figure 7. The linear regression equation was illustrated by the equation as follows:

$$y = -1235x + 207.8 \quad (1)$$

$$R^2 = 0.772$$

where y = cube compressive strength at 28 days (kg/cm^2), x = percentage of plastic waste (%).

The linear equation model can represent the correlation between the compressive strength. Besides, this linear equation can be able to predict the compressive strength of CC and WPMC by plugging the % of the percentage of additive waste plastic into the equation.

3.3 Carbon dioxide equivalent (CO_2e)

Stephen Leung [6] proposed CO_2e of particular constituents of concrete as shown in Table 3.

3.4 CO_2 -emission assessment determination

The evaluation of CO_2 emission (tCO_2/m^3 -concrete) can be determined by the multiplication of CO_2e (tCO_2/t) and each constituent amount in the concrete mix (tCO_2/m^3) as shown in Table 4.

From Table 4, the CO_2 emission of conventional concrete (CC) is $0.25 \text{ tCO}_2/\text{m}^3$ of concrete which is higher than waste PET mixed concrete (WPMC with 1%, 2%, 3%, 4% and 6% PET content) that are 0.24, 0.23, 0.22, 0.21 and $0.19 \text{ tCO}_2/\text{m}^3$ respectively.

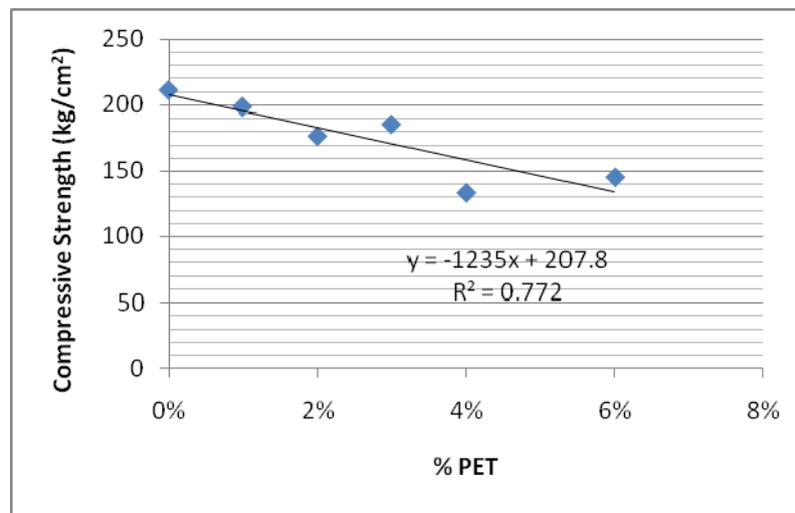


Figure 7 Linear correlation between compressive strength and % of plastic waste

Table 3 CO_2e of concrete constituents

Material	CO_2e (tCO_2/t)
Portland Cement	0.822
Coarse aggregate	0.008
Fine aggregate	0.0053
Water	0.000000249
PET-bottle waste	-3.38*

*The minus sign of this value mean that PET-bottle waste utilization can be reduced CO_2 from saving of energy for recycling process. This value can be calculated based on the utilization of PET bottle waste can be reduced the energy 60 MJ/kg refers to [12]. It can be converted to be the CO_2 emission reduction equal to 3.38 kg- CO_2 per kg of PET bottle waste as referred to [13]. The CO_2 emission from waste PET crusher is 0.00071 kg- CO_2 per kg of PET, and then this value is slight figure compare to the value from PET-bottle waste recycling, then it is not inclusive value in this calculation.

Table 4 CO_2 emission evaluation of the concrete mixes

Mix	CO_2 -emission of constituent (tCO_2/m^3 -concrete)					Total CO_2 -emission (tCO_2/m^3 -concrete)
	Cement	Coarse aggregate	Fine aggregate	Water	PET	
CC (0% PET)	0.24	0.0087	0.0042	0.00005	0.00	0.25
WPMC (1% PET)	0.24	0.0087	0.0042	0.00005	-0.01	0.24
WPMC (2% PET)	0.24	0.0087	0.0042	0.00005	-0.02	0.23
WPMC (3% PET)	0.24	0.0087	0.0042	0.00005	-0.03	0.22
WPMC (4% PET)	0.24	0.0087	0.0042	0.00005	-0.04	0.21
WPMC (6% PET)	0.24	0.0087	0.0042	0.00005	-0.06	0.19

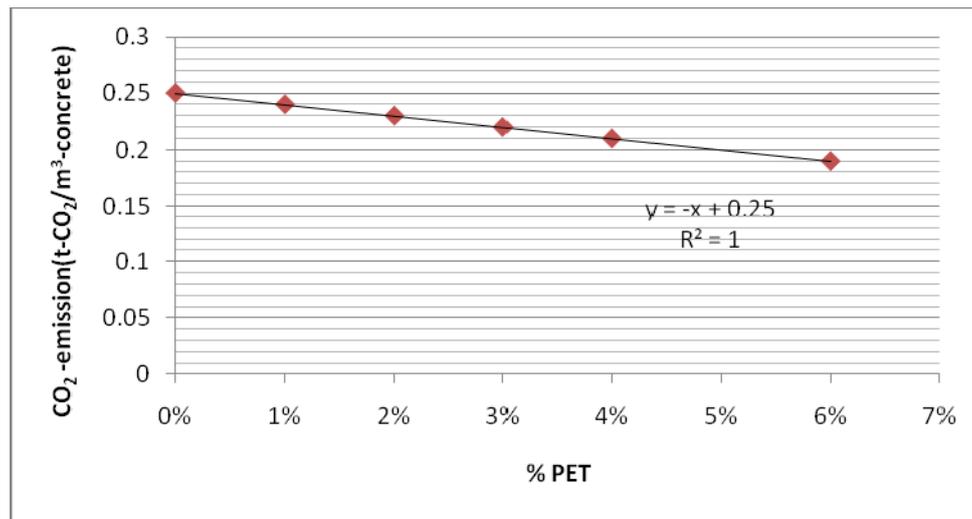


Figure 8 Linear regression line between CO₂ emission of concrete mix and % of plastic waste

Table 5 CO₂-emission of concrete mix and % PET content

Mix Type	% PET Content By weight of cement	CO ₂ -emission quantity (ton-CO ₂ /m ³)
CC (0% PET)	0.00	0.25
WPMC (1% PET)	1.00	0.24
WPMC (2% PET)	3.00	0.23
WPMC (3% PET)	3.00	0.22
WPMC (4% PET)	4.00	0.21
WPMC (6% PET)	6.00	0.19

Table 6 Strength ratio and equivalent CO₂-emission determination of CC and WPMC

Mix Type	PET Waste Compressive Strength (kg/cm ²)	WPMC/CC Compressive Strength ratio (%)	CO ₂ -emission Quantity (ton-CO ₂ /m ³)	CO ₂ -emission Reduction Rate (%)
CC (0% PET)	211.00	100.00	0.25	0.00
WPMC (1% PET)	198.43	94.04	0.24	4.17
WPMC (2% PET)	176.33	83.57	0.23	8.70
WPMC (3% PET)	185.37	88.00	0.22	13.64
WPMC (4% PET)	133.07	63.07	0.21	19.05
WPMC (6% PET)	145.00	68.72	0.19	31.60

3.5 The correlation between CO₂ emission and % PET waste content

The CO₂ emission of each concrete mix and the percentage of a crushed waste PET fraction are summarized in Table 5.

The CO₂ emission of concrete mixes for 0%, 1%, 2%, 3%, 4% and 6% of crushed PET content can be illustrated by linear equation model which is established by simple regression analysis as shown in Figure 8.

The equation illustrated the linear correlation as following:

$$y = -x + 0.25 \quad (2)$$

$$R^2 = 1.00$$

where y = CO₂ emission (ton-CO₂/m³ of concrete),
 x = percentage of plastic waste (%).

3.6 The balance between CO₂-emission of concrete mixed and % waste PET content

The compressive strength ratio between WPMC and CC of the compressive strength of concrete mixes and CO₂-emission reduction of WPMC compared with CC can be determined as shown in Table 6.

The correlation between CO₂ emission reduction and % crushed waste PET content of concrete mixes for CC and WPMC can be illustrated by linear equation model which is established by simple regression analysis and the extrapolation as shown in Figure 10.

The linear regression equation was represented by following:

$$y_1 = 5.251x - 0.011 \quad (3)$$

$$R^2 = 0.992$$

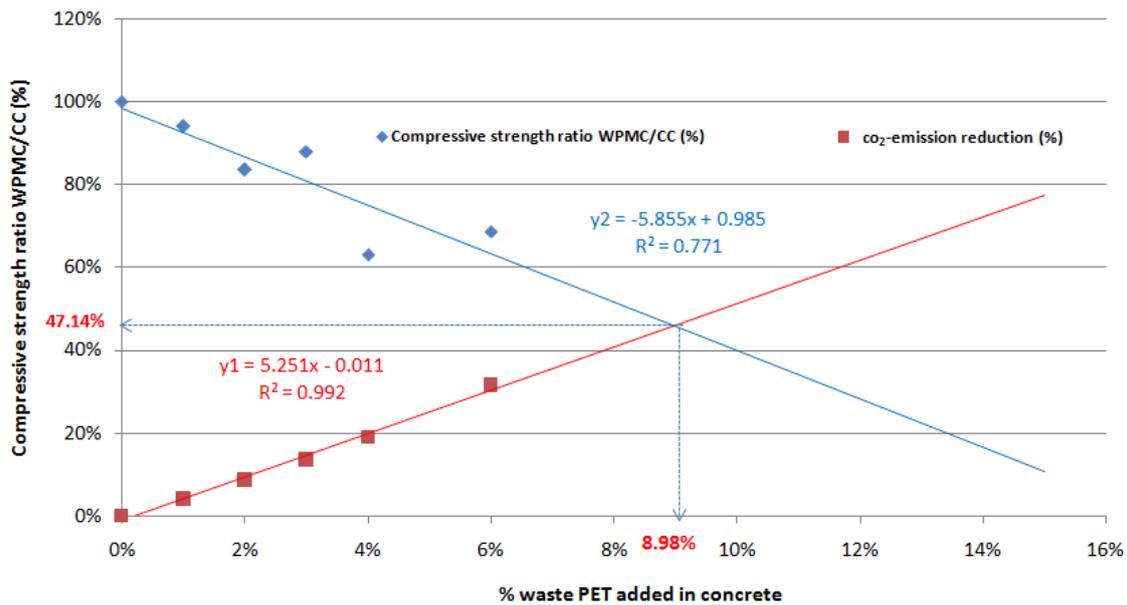


Figure 9 Linear regression line of CO₂ emission reduction and strength ratio to find the balance point

y1 means CO₂ emission reduction (kg-CO₂/m³ of concrete) and x means percentage of plastic waste (%).

The correlation between compressive strength ratio and % crushed waste PET content of concrete mixes for CC and WPMC can be illustrated by linear regression analysis and the extrapolation as shown in Figure 9.

The linear regression equation was shown as following:

$$y_2 = -5.855x + 0.985 \quad (4)$$

$$R^2 = 0.771$$

y2 means Compressive strength ratio WPMC/CC (kg/cm²) and x means percentage of plastic waste (%).

At the intersection of both linear regression lines $y_1 = y_2$, that derived x from equality of both equations then gain $x = 8.98\%$ and plugging $x = 8.98\%$ into each equation to find the strength ratio. The compressive strength ratio at the equilibrium of (3) and (4) is 47.14% with 8.98% of crushed waste content become the balance point of CO₂ emission (Equivalent zero emission of CO₂ of the concrete mix).

4. Conclusions

The following conclusions of this study based on the experiment and the assessment results.

4.1 The cube compressive strength of concrete contained crushed waste PET was lower than conventional concrete (CC). The correlation between a compressive strength of waste PET mixed concrete (WPMC) and PET content (%) are a linear relationship and can be predicted by the percentage of crushed waste PET fraction by weight of cement added in concrete as an additive constituent.

4.2 The CO₂ emission of the concrete contained crushed waste PET was lower than conventional

concrete (CC). The correlation between CO₂ emission quantity of waste PET mixed concrete (WPMC) and PET content (%) are linear correlation and can be predicted by the percentage of crushed waste PET fraction by weight of cement added in concrete as an additive constituent by the CO₂ emission assessment of concrete mixes.

4.3 The CO₂ emission reduction of concrete contained crushed waste PET 1%, 2%, 3%, 4% and 6% were 4.17%, 8.70%, 13.64%, 19.05% and 31.60% lower than conventional concrete (CC) respectively while the compressive strength ratio of WPMC (1%, 2%, 3%, 4% and 6% PET) were 94.04%, 83.57%, 88.00%, 63.07% and 68.72% of CC strength respectively. From regression analysis and extrapolation of the linear correlation between CO₂ emission reduction and a strength ratio of concrete mixes found that the compressive strength ratio at 47.14% of with 8.98% of crushed PET waste content in concrete became the balance point of CO₂ emission (Equivalent zero emission of CO₂ of a concrete mix).

4.4 In waste reduction viewpoint, the waste PET utilization as the additive constituent in concrete may be useful recycling concept. The CO₂ emission reduction from a using of crushed waste PET material can be helpful for waste management as well as a development the alternative direction for concrete material.

4.5 From the compressive strength trend, the application of the concrete contained crushed waste PET shall be non structural concrete product such as concrete ditch, walk way, concrete curb etc. However, the further study shall be extended to the compressive strength improvement of PET- concrete as well as low CO₂ emission.

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