Applied Mechanics and Materials Vols. 253-255 (2013) pp 408-416
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.253-255.408

Development of Mix Design Nomograph for Polyethylene Terephthalate Fiber Concrete

J.M. Irwan[1a], N. Othman[2b], H.B. Koh[3c], R.M. Asyraf[4d] Faisal S.K[5e], M.M.K. Annas[6f], A.M. Shahrizan[7\g]

[1, 2, 3, 4, 5, 6, 7] Faculty of Civil and Environmental Engineering, University Tun Hussein Onn Malaysia

[a, b, c, d, e, f, g]irwan@uthm.edu.my [a], norzila@uthm.edu.my [b], koh@uthm.edu.my [c], asyraf178@gmail.com[d], fai.arisal@gmail.com[e], annas@gmail.com[f], shahrizan@kktmsrigading.edu.my[g]

Keywords : Fiber concrete, polyethylene terephthalate (PET), compressive strength, splitting tensile, nomograph, water-cement ratio

Abstract - The aim of this project was to develop of mix design nomograph for PFC that can be used for estimated the required compressive strength and splitting tensile strength with the required PET and water-cement-ratio.The fibers were prepared by using plastic granulator machine SLM 50 FY with size passing 10 mm and retained 5 mm sieve. Different volumes percentages of PET fibers with 0%, 0.5%, 1.0% and 1.5%, were introduced in concrete mixes. The specimens prepared for this study was cylinder concrete with 100 mm diameter and 200 mm height. The laboratory work for physical properties were focused on density and workability, meanwhile for mechanical properties were focused on compressive strength, splitting tensile strength and modulus of elasticity of PET fiber concrete (PFC). The experiment results indicate that the addition of PET fibers significantly decreased the compressive strength and splitting tensile, however the compressive strength still can be acceptable since achieved the mix design The nomograph developed can be used to estimate the desired compressive, splitting tensile strength as well as the modulus of elasticity (MOE).

1. Introduction

Polyethylene terephthalate (PET) is one of the most common consumer plastics used and is widely employed as a raw material to realize products such as bottles soft-drink use and containers. PET bottles have taken the place of glass bottles as storing vessel of beverage due to its lightweight and easiness of handling and storage. In 2007, it is reported that world's annual consumption of PET drink covers of approximately 10 million tons, which presents perhaps 250 milliards bottles. This number grows about up to 15% every year [2].

World widely, the number of recycled or returned bottles is very low. Generally, the empty PET packaging is discarded by the consumer after use and becomes PET waste (WPET). The major problems that this level of waste production generates initially entail storage and elimination except thermoplastic product [3]. In the case of thermoplastic products, regeneration can be feasible. Other technique is based on recycling, which supposes that the waste has been presorted and potentially transformed to new materials. The sorted post-consumer PET waste is crushed, pressed into bales and offered for sale to recycling companies. Recycling companies will further treat the post-consumer WPET by shredding thematerial into small fragments. WPET flakes are used as raw material for a range of products [1].

Various studies investigated possibility of waste plastic in other material. Ochi et al., [4] investigated the possibility of using various plastic wastes containing high-density polyethylene (HDPE) as polymer additives to asphalt concrete. The results indicated that waste HDPE-modified bituminous binders provide better resistance against permanent deformations due to their high stability and high Marshal Quotient [3]. A different study use the waste PET bottles as PET fibers to produce fiber reinforced concrete with the aim to increase the toughness of concrete [4-5]. The use of fibers made by waste PET bottles in fiber reinforced concrete is also able to control the plastic shrinkage cracking in cement- based composites [5-6]. Marzouk et al., [1] study on the use of waste

PET as fine aggregate. The fine aggregate was replaced by the same volumetric percentage of recycled PET. The result demonstrated that plastic particles may be successfully used as sand-substitution aggregates in cementitious concrete. It was initially seen that, once the sand volume substituted with WPET aggregates increased from 0% to 50%, the compressive strength of mortar slightly decreased about 16%, in comparison with the reference mortar. For 50% substitution of WPET, result decrease reaches 32.8%.

The above statement proved the potential used of PET waste in various field as a better option in compare to dispose to landfill [6]. This paper, highlighted on knowledge about engineering properties and development of mix design nomograph of concrete containing PET wastes.

2. Experimental

2.1Materials

The PET fiber is taken and prepared from mineral bottles as an additional material in concrete. This bottle was cut manually approximately 30 mm size as before crush into irregular shape using granulated machine. In order to accomplish this objective, pilot tests were conducted by addition PET fibers with different volume fraction to identify the optimum addition PET fibers in concrete. The amounts of volume fraction of PET fiber used in this study are 0.5%, 1.0% and 1.5% with three different water-cement ratios namely is 0.45, 0.55 and 0.65.

2.2 Concrete Mix Design

In this research, Ordinary Portland cement, fine aggregate, course aggregate and three (3) different volumes fraction of PET (0.5%, 1.0% and 1.5%) with three (3) water-cement ratio at 0.45, 0.55 and 0.65 were used in the mix proportion of concrete. Mix proportion design based on Department of Environment (DOE) for concrete was indicated in Table 1. Quarry sand was used as fine aggregate and crushed gravel with size less than 40 mm was used as coarse aggregate. The summarized of mix proportion of concrete is shown in Table 1.

Table 1: Mix proportion of concrete

Specimens	w/c	Unit Weight (kg/m^3)				PET volume fraction	
		Cement	Fine Aggregate	Coarse Aggregate	Water	(%)	(kg)
Normal Concrete	0.45				133	0.5	-
	0.55				163	1.0	-
	0.65				192	1.5	-
F_{PET} 0.5	0.45				133	0.5	0.001414
	0.55				163	1.0	0.002828
	0.65				192	1.5	0.004242
F_{PET} 1.0	0.45	295	885	1085	133	0.5	0.001414
	0.55				163	1.0	0.002828
	0.65				192	1.5	0.004242
F_{PET} 1.5	0.45				133	0.5	0.001414
	0.55				163	1.0	0.002828
	0.65				192	1.5	0.004242

3. Analysis and results

3.1 Testing of Fresh Concrete

3.1.1 Density

Table 2 indicates the density of PFC is decreased with the increase of fiber content. The density of fiber concrete comparing with normal concrete reduce by 0.07%, 0.43% and 0.67% for concrete with water cement ratio 0.45, reduced by 0.29%, 0.39% and 0.53% for concrete with water cement ratio

0.55 and reduced by 0.36%, 0.87% and 1.09% for concrete with water cement ratio 0.65 for 0.5%, 1.0% and 1.5% PET added to concrete respectively. Similar findings on the effect of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) by Choi *et al.* [7], they found that the density of concrete mixtures decreased with the increased in WPLA content. Studies obtained by Castro-Gomes [8] on utilization of PET bottles recycled as fiber reinforced renders mortar, as a result the fiber addition causes a small decrease in density such reduction not exceed 5% even for 1.5% fiber volume. This study agree with previous studies that the decrease of concrete density or will lower unit weight of the plastic use.

3.1.2 Slump test

The slump data for the mixture are recorded in millimeters as shown in Table 2. Based on the data from Table 2, it is clearly indicates that the slump of the mixture is decreased when the amount of PET fibers content increase. This shows that the workability of the mixture is decreased by adding PET fibers in the mixture. Slump height for the control specimen which is plain concrete was 25mm for 0.45 water cement ratio, 35mm for 0.55 water cement ratio and 40mm for 0.65 water cement ratio. Slump reduction for concrete mixture compared to normal concrete with 0.45 water-cement ratio was 20%, 60% and 80%, for 0.55 water-cement ratio was 3%, 14% and 29% and for 0.65 water-cement ratio was 5%, 25% and 38% for volume fraction 0.5%, 1.0% and 1.5% PET added to concrete respectively.

Table 2: Density and slump test for PET fiber concrete

Specimens	Fiber Volume (%)	Density (Kg/M³)	Reduction Of Density (Kg/M³)	Reduction Percentage %	Slump Height (Mm)	Slump Reduction
$PFC1_{\_0.45}$	0	2387.24	0	0	25	0%
$PFC2_{\_0.45}$	0.5	2385.66	1.58	0.07	20	20%
$PFC3_{\_0.45}$	1	2377.06	10.17	0.43	10	60%
$PFC4_{\_0.45}$	1.5	2371.28	15.96	0.67	5	80%
$PFC1_{\_0.55}$	0	2372.68	0	0	35	0%
$PFC2_{\_0.55}$	0.5	2365.84	6.84	0.29	34	3%
$PFC3_{\_0.55}$	1	2363.39	9.29	0.39	30	14%
$PFC4_{\_0.55}$	1.5	2360.05	12.63	0.53	25	29%
$PFC1_{\_0.65}$	0	2381.1	0	0	40	0%
$PFC2_{\_0.65}$	0.5	2372.5	8.59	0.36	38	5%
$PFC3_{\_0.65}$	1	2360.23	20.87	0.87	30	25%
$PFC4_{\_0.65}$	1.5	2355.14	25.96	1.09	25	38%

3.2 Testing of hardened concrete

3.2.1 Compressive strength

The compressive strength test is measured accordance to ASTM C 39M – 013. The result of compressive strength test of concrete cylinder 100 mm diameter and 200 mm length with different volume fraction of PET fiber at 7, 14 and 28 days are shown in Table 3. Table 3 shows the compressive strength versus age of each volume fraction with water-cement ratio 0.45, 0.55 and 0.65. It can be seen that the maximum compressive strength at age 28 days for all the specimens almost same and consistent within range 25.1 MPa to 28.3 MPa. However for normal concrete with water-cement ratio 0.45 has the highest compressive strength which is 39.3 MPa. After sample loaded with applied force it is observed that most samples has crack pattern cone & shear and cone & split. The crack pattern for normal concrete and PFC can be concluded has similar crack pattern. The tested From ASTM C 39, cone & shear and cone & split are fairly typical fracture for normal concrete.

Concrete mixtures were made with different water cement ratio and varying percentage volume fraction of PET fiber shows the compressive strength decreased with increased volume fraction of PET and the compressive strength was found decrease when the water-cement ratio increase. There are 30%, 0.7% and 1.2% reduction in the compressive strength for concrete containing 0.5%, 1.0% and 1.5% of PET fiber respectively. The reduction in compressive strength might be due to either a poor bond between cement pastes with PET fiber and cause the low strength of PET fiber characteristic. Soroushian *et al.* [9] demonstrated that compressive strength of concrete decreased with the inclusion of recycled plastic in it. Al- Manaseer and Dalal [10] investigated the effects of inclusion of plastic aggregates on the compressive strength of concrete and founded at any given plastic aggregates content, the compressive strength was found to decrease when the water-cement ratio was increased. The result for this study is agreed with the studies conducted by Soroushian *et al.* [9] and Al- Manaseer and Dalal [10], that the increased of fiber volume and water-cement ratio in concrete will affect the loss in compressive strength of concrete.

Table 3: Compressive strength of PET Fiber Concrete

	Compressive Strength, MPa											
w/c ratio	0.45				0.55				0.65			
Volume Fraction / Age (day)	0	0.5	1	1.5	0	0.5	1	1.5	0	0.5	1	1.5
7	12.8	21.2	18.0	19.9	19.6	19.1	18.9	18.8	16.4	15.7	9.1	14.4
14	23.2	21.8	21.8	23.4	22.5	23.9	22.9	22.8	19.8	16.5	18.8	16.3
28	39.3	26.8	27.9	27.4	26.7	27.4	28.3	26.5	25.4	25.2	24.6	25.1

3.2.2 Splitting tensile strength

This method consists of applying a diametric compressive force along the length of cylindrical specimen size with 100 mm diameter and 200 mm length was tested according to BS 1881: Part 117: 1983. The average values splitting tensile strength for 28 days as indicate in Table 4. From Table 4, it shows that the splitting tensile increase with decrease of PET fiber. In the case of water-cement ratio 0.45 the splitting tensile was 3.65 MPa, 3.57 MPa, 3.50 MPa and 2.56 MPa, water-cement ratio 0.55 the splitting tensile was 3.52 MPa, 2.98 MPa, 2.87 MPa and 2.74 MPa and water-cement ratio 0.65 the splitting tensile was 3.43 MPa, 3.24 MPa, 2.60 MPa and 2.37 MPa with contained PET fiber 0%, 0.5%, 1.0% and 1.5% PET added respectively. Choi *et al.* [7] studied the influence of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the splitting tensile strength of concrete. It is clear that splitting tensile strength of concrete mixtures decreased with the increase in PET aggregates and for a particular PET aggregate content, splitting tensile strength increased with the reduction in water-cement ratio. On the other hand, Al-Manaseer and Dalal [10] studied the effects of plastic aggregates on the splitting tensile strength of concrete where concrete made with different water-cement and various percentages of plastic aggregates. They concluded that splitting tensile strength decreased with the increase in plastic aggregates percentage and for a given plastic aggregate content, the splitting tensile strength was found to decrease when water-cement was increased. It can be pointed out that, the variation of splitting tensile strength of the plastic waste concrete obtained from all finding in the range 2 to 5 Mpa. Therefore the result obtained from this study was acceptable and can be concluded as the decrease of splitting tensile strength with increased of plastic in concrete and water-cement ratio.

Table 4: Splitting tensile strength of PET Fiber Concrete

w/c %	Volume &	Load (kN)	Area (m2)	Strength MPa	Tensile MPa
0.45	0	114.63	0.00785	14.60	3.65
	0.5	112.18	0.00785	14.28	3.57
	1.0	109.95	0.00785	14.00	3.50
	1.5	80.46	0.00785	10.24	2.56
0.55	0	110.49	0.00785	14.07	3.52
	0.5	93.57	0.00785	11.91	2.98
	1.0	90.07	0.00785	11.47	2.87
	1.5	85.97	0.00785	10.95	2.74
0.65	0	107.91	0.00785	13.74	3.43
	0.5	101.91	0.00785	12.98	3.24
	1.0	81.59	0.00785	10.39	2.60
	1.5	74.38	0.00785	9.47	2.37

3.2.3 Modulus of elasticity (MOE)

The modulus of elasticity (MOE) defined as the ratio of the normal stress to corresponding strain below the proportional limit. For practical purposes, only the deformation which occurs during loading is considered to contribute to the strain in calculating the normal load rate modulus of elasticity. In this laboratory assessment, twelve (12) different fiber concrete mixtures including three (3) normal concrete mixture which is 0.45, 0.55 and 0.65 water-cement ratio are used to collect and the data and gather the detail value as shown in Table 5. According to Table 5, its can be summarized that the lowest modulus of elasticity is 17 GPa which is for specimen PFC4$_{0.55}$ and PFC4$_{0.65}$ and the highest modulus of elasticity is 33 GPa for specimen PFC1$_{0.45}$. In compare to the rest specimens, the result shows the data was acceptable since still in range 19 GPa to 31 GPa and be able to consider acceptable according to BS8110 - 2: 1985. The result of modulus of elasticity of concrete containing different percentages of PET can be concluded as the modulus of elasticity decreased with the increase of PET content in concrete. It also shows that as water-cement ratio increase than the modulus of elasticity of concrete decrease. The results of this research is similar to the previous study by others researcher Choi et *al.* [7], that modulus of elasticity of concrete mixtures decreased with the increase in PET aggregates.

Table 5: Summary of modulus of elasticity (MOE)

Modulus of Elasticity, GPa			
	Water-Cement Ratio (%)		
Specimen	0.45	0.55	0.65
PFC1	33	29	28
PFC2	29	24	21
PFC3	26	23	20
PFC4	18	17	17

3.3 Mix design of Development Nomograph

The major contribution of this study is constructed the nomograph of age 28 days polyethylene terephthalate fiber concrete. To develop this nomograph, it's needs several data of an experiment that has been conducted and analyzes before such as compressive strength, splitting tensile, water-cement ratio and volume fraction of PET. The nomograph consist four (4) relationship developed from the fresh and hardened concrete into one graph as shown in Fig. 1. The relationships were compressive strength versus water-cement ratio, compressive strength versus PET percentage, tensile strength versus water-cement ratio and tensile strength versus PET percentage. The relationship between compressive strength and water cement ratio is plotted by referred to Abrams' law by J. Hu *et al* [11]. Abrams' law correlates the compressive strength of concrete with the water cement ratio in power expression in Eq. 1.

$$f'c = \frac{k_1}{k_2^{\frac{w}{c}}}$$

where k_1 and k_2 are constants depending on the materials used (1)

Meanwhile for the others relationship is developed by referred to best line fit to all data plotted into the nomograph. Fig. 1 shows the preliminary recommended nomograph for concrete mix design polyethylene terephthalate fiber concrete. The nomograph can be used to determine the concrete mix proportion for a required compressive strength and splitting tensile strength. For confirmation purposes, the value obtained by nomograph is compared to the value obtained experimentally as tabulated in Table 6. The data obtained experimentally than compared with data obtained by using nomograph. The plotted nomograph then was checked by taking the PET value as initial reading from the relationship between splitting tensile strength versus PET percentage, and then finish at same axis. The mix design nomograph developed can help field engineers select the proper mix proportion parameters to meet specified concrete performance criteria. However, in this study only early predicted nomograph developed due to the limitation of sample, time and parameters tested.

To ensure the accuracy of the new development of nomograph, the known data from previous studies are used to compare with data from nomograph as shown in Fig. 1. The PET percentage which is 0.5%, 1.0% and 1.5% were taking as initial reading to identify the compression strength and splitting tensile results. The value of compression strength and splitting tensile from nomograph than taken and compared it with the experimental result as shown in Table 6. Table 6 shows the value of compressive and tensile strength obtained from nomograph and experimental was inaccuracy, however the percentage difference is below than 10%. For PFC contained PET volume 0.5%, 1.0% and 1.5%, it shows the percentage difference was 7.6%, 4.6% and 0.3% for compression strength meanwhile for splitting tensile strength; it shows the percentage difference was 7.7%, 2.7% and 7.1%.

Table 6: Comparison between Nomograph and Experimental

PET %	w/c ratio %	Compression Strength, Mpa			Splitting Tensile Strength, Mpa		
		Nomograph Value	Experiment Value	Percentage Difference	Nomograph Value	Experiment Value	Percentage Difference
0.5	0.45	29.0	26.8	7.60%	3.3	3.57	7.70%
1	0.55	27.0	28.3	4.60%	2.95	2.87	2.70%
1.5	0.65	25.0	25.1	0.30%	2.55	2.37	7.10%

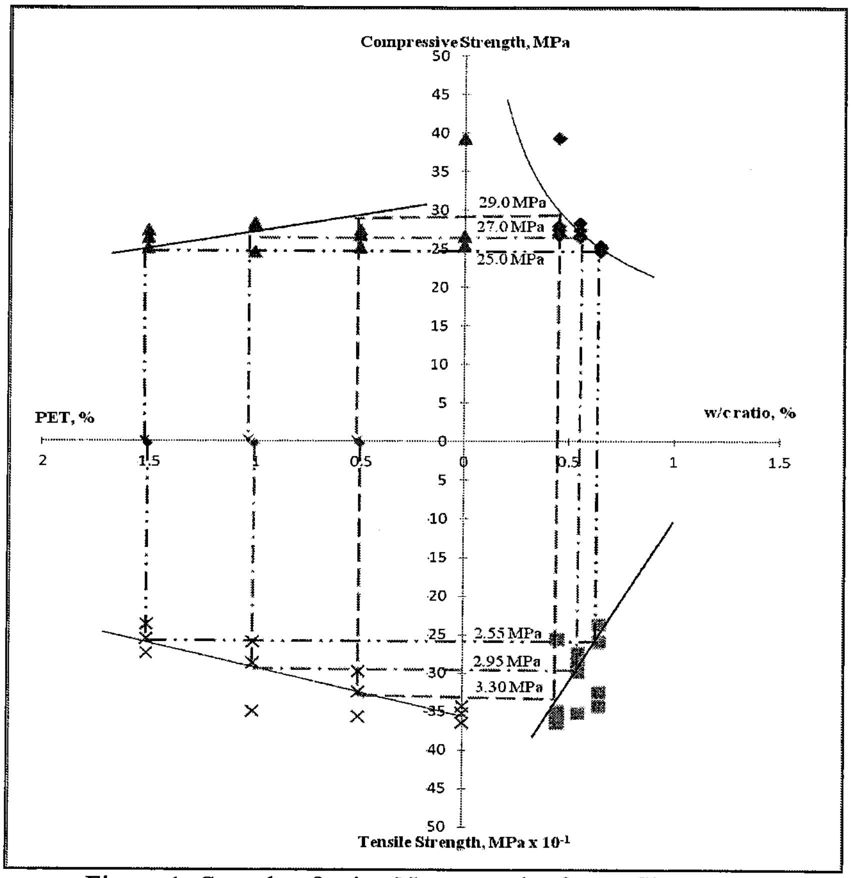

Figure 1: Sample of using Nomograph of PET fiber concrete

4. Conclusion

This research represented the physical and mechanical properties of polyethylene terepthalate fiber concrete and development of nomograph. The physical properties tested were workability and density of PFC and the mechanical properties tested focused on compressive strength, splitting tensile and Modulus of elasticity. From the study and experiment that has been conducted, the conclusions are:-

i. Physical Properties:

- It has founded the densities of Polyethylene Terepthalate Fiber Concrete (PFC) is lower than normal concrete and the reduction of PFC densities with the increased of PET materials in concrete. As present discuss, from the others studies by Choi *et al.* [7], Al-Manaseer and Dalal [10], and LA. Pereira and J. P. Castro-Gomes [8] they founded the decrease of concrete density with increase the volume fraction of plastic. This occurs because of attributed to the lower unit weight of the plastic use.

- On the other hand the workability of concrete can be concluded as the reduction of concrete workability with added plastic materials in concrete mixture. Its same finding from others studies, Soroushian *et al.* [9] and Mehta and Monteiro [12] has reported and agreed the loss of slump test with addition plastic in concrete same as this study.

ii. Mechanical Properties

- Compressive strength of concrete at age 28 days, it can be concluded as the increased of fiber volume and water-cement ratio in concrete will affect the loss in compressive strength of concrete. However the compressive strength of PFC still considered acceptable since the strength exceed 25 MPa where all specimens consistent within range 25.1 MPa to 28.3 MPa except for normal concrete with water cement ratio 0.45 has the highest compressive strength which is 39.3 MPa.

- Regarding to discussion before, the result obtained from this study was acceptable within range 2 to 5 MPa. Same as others researcher finding, it can be concluded as the decrease of splitting tensile strength with increased of plastic in concrete and water-cement ratio.

- The result of modulus of elasticity of concrete containing different percentages of PET can be concluded as the modulus of elasticity decreased with the increase of PET content in concrete and increase in water-cement ratio than decreased the modulus of elasticity of concrete.

iii. Development of nomograph

- A variety of concrete mixes was made with three different volume fractions of PET fiber and three difference water-cement ratios. The concrete workability, compressive strength and splitting tensile of concrete mixes were evaluated and based on the test results the mix design nomograph was developed.

- The mix design nomograph developed in this study should be doing a further study to get more accurate nomograph. Based on nomograph that has been developed it was have some inaccuracy data when added with fiber 0.5%, 1.0% and 1.5% which is for compression test was 7.6%, 4.6% and 0.3% and for splitting tensile test was 7.7%, 2.7% and 7.1% compared to experimental result. However by this research finding, it may help for others researcher as references and guideline for their further studies.

Acknowledgements

This work was financially supported by the University of Tun Hussien Onn Malaysia (UTHM) and the Ministry of Higher Education Malaysia (KPT).

References

[1] Marzouk O, Dheilly R, Queneudec M. Valorization of post-consumer waste plastic in cementitious concrete composites. Waste Manage 2007; 27:310–8.

[2] ECO PET, 2007. http://www.ecopet.eu/Domino_english/ecopet.htm

[3] Hınıslıoglu, S., Ag'ar, E., 2004. Use of waste density polyethylene as bitumen modifier in asphalt concrete mix. Materials Letters 58 (3–4), 267–271.

[4] Ochi T, Okubo S, Fukui K. Development of recycled PET fibre and its application as concrete-reinforcing fibre. Cement Concr Compos 2007; 29:448–55

[5] Silva D, Betioli A, Gleize P, Roman H, Gomez L, Ribeiro J. Degradation of recycled PET fibers in Portland cement-based materials. Cem Concr Res 2005; 35:1741–6.

[6] Fernando, P.T., Castro Gomes, J.P., Said, J., 2008. Adhesion characterization of tungsten mine waste geopolymeric binder. Influence of OPC concrete substrate surface treatment. Construction and Building Materials 22 (3), 154–161.

[7] Choi, Y.W., Moon, D.J., Chumg, J.S., Cho, S.K., 2005. Effects of waste PET bottles aggregate on the properties of concrete. Cement and Concrete Research 35, 776–781.

[8] LA Pereira de Oliveira and J.P. Castro Gomes., 2011. Physical and mechanical behavior of Recycled PET fiber reinforced mortar. Construction and Building Materials 25, 1712–1717.

[9] Soroushian, P., Plasencia, J., Ravanbakhsh, S., 2003. Assessment of reinforcing effects of recycled plastic and paper in concrete. ACI Materials Journal 100 (3), 203–207.

[10] Al-Manaseer, A.A., Dalal, T.R., 1997. Concrete containing plastic aggregates. Concrete International 19 (8), 47–52.

[11] J. Hu, K. Wang, J.A. Gaunt. 2012. Behavior and mix design development of concrete made with recycled aggregate from deconstructed lead-contaminated masonry materials. Construction and Building Materials pg 1–5.

[12] Monteiro PJM, Helene PRL, Kang SH., 1993. Designing concrete mixtures for Strength, elastic modulus and fracture energy. Material Structure 26:443–52.