FLEXURAL BEHAVIOUR OF POLYETHYLENE TEREPHTHALATE (PET) FIBRE IN CONCRETE

KUAH YI MEI

Thesis submitted in fulfilment of the requirements
for the award of the degree of
B.Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2015

ABSTRACT

Today there are still many issues about landfill capacity problem. The global has the same mission in reducing the land capacity of world. Plastic waste is 24% over 17,000 of total municipal waste in Malaysia. Plastic waste has a slow degradation rate. This means that plastic waste is a compound which is hard to decompose in landfill. Polyethylene terephthalate (PET) is one type of plastic which is made by virgin plastic usually used to packaging of drink. According to Lesley McFadzean the decompose rate of a plastic bottle is 450 years. These mean that PET will occupy the landfill capacity with 450 year. In this development generation, plastic bottle still used widely and is a life essential for human. There are many countries had tried to reduce the number of PET, such as China created bottle-recycling vending machines and United State form National Association for PET Container Resources (NAPCOR) to reduce the PET's waste. They are finding an alternative ways to reduce PET in landfill capacity. Using PET in construction material is not fresh in the global. In Japan they use PET to spraying and lining of tunnels. In this study PET is used as fibre to investigate the flexural behaviour of concrete. The objectives of this study are: (a) to determine the flexural strength of concrete which have addition of PET strip (b) to determine the performance of different length of PET strip in concrete (c) Compare the flexural strength of conventional and addition of PET strips concrete. The PET is hand cut into 10mm width and 20 mm, 40 mm and 60 mm length. The slump test, flexural test and compression test were carried out to indicate the performance of concrete. The results show that the increase in length of PET fibre the: (a) compressive strength increase (b) flexural strength increase (c) crack width control improved (d) ductility of concrete increase.

ABSTRAK

Hari ini, masih terdapat banyak isu tentang masalah kapasiti tapak pelupusan. Global dengan misi sama dalam mengurangkan kapasiti tapak pelupusan dunia. Sisa plastik adalah 24% lebih 17,000 daripada jumlah sisa perbandaran di Malaysia. Sisa plastik mempunyai kadar kemerosotan yang perlahan. Ini bermakna bahawa sisa plastik adalah sebatian yang keras untuk mengurai di tapak pelupusan. Polyethylene Terephthalate (PET) adalah salah satu jenis plastik yang diperbuat oleh plastik dara biasanya digunakan untuk pembungkusan minuman. Menurut Lesley McFadzean kadar mengurai daripada botol plastik adalah 450 tahun. Ini bermakna bahawa PET akan menduduki kapasiti tapak pelupusan dengan 450 tahun. Dalam perkembangan ini generasi botol plastik masih digunakan secara bijak dan kehidupan yang penting untuk manusia. Terdapat banyak negara telah cuba untuk mengurangkan bilangan PET, seperti China mencipta mesin bottle-recycling vending dan negeri United bentuk Persatuan Kebangsaan bagi PET Container Resources (NAPCOR) untuk mengurangkan sisa PET itu. Mereka mendapati satu cara alternatif untuk mengurangkan PET dalam kapasiti tapak pelupusan. Menggunakan PET dalam bahan pembinaan tidak segar dalam global. Jepun telah menggunakan PET sebagai pengisi terowong .Dalam kajian ini PET digunakan sebagai gentian untuk menyiasat kelakuan lenturan konkrit. Objektif kajian ini adalah: (a) Untuk menentukan kekuatan lenturan konkrit yang mempunyai penambahan jalur PET. (B) Untuk menentukan prestasi panjang yang berbeza jalur PET dalam konkrit. (C) Bandingkan kekuatan lenturan konvensional dan penambahan PET jalur konkrit. PET adalah potong tangan ke dalam lebar 10mm dan 20mm, 40mm dan 60mm panjang. Ujian kemerosotan, ujian lenturan dan mampatan ujian telah dijalankan untuk menunjukkan prestasi konkrit. Keputusan menunjukkan bahawa peningkatan dalam panjang PET serat yang: (a) peningkatan kekuatan mampatan (b) peningkatan kekuatan lenturan (c) retak kawalan lebar bertambah baik (d) kemuluran kenaikan konkrit.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percentage
mm	Millimeter
N/mm^2	Newton per millimeter square
kg	Kilogram
N	Newton
℃	Degree Celsius
∑	Sum
w/c	Water to cement ratio
mm^2	Millimeter square
min	Minute
µm	Micrometer
MPa	Mega Pascal
±	Plus-Minus

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standard
CEM	Certified Energy Manager
CO_2	Carbon Dioxide
DOC	Dissolved Organic Carbon
EN	European Standards
FPZ	Fracture Process Zone
JPSPN	Jabatan Pengurusan Sisa Pepejal Negara
LVDT	Linear Variable Differential Transformer
MS	Malaysia Standard
NA	Natural Aggregate
NAPCOR	National Association for PET Container Resources
NH3	Ammonia
OPC	Ordinary Portland Cement
PET	Polyethylene Terephthalate
PP	Polypropylene
PPFRC	Polypropylene Fibre Reinforced Concrete
PVA	Polyvinyl Alcohol
RPETFRC	Recycled PET Fibre-Reinforced Concrete
XOC_3	Xenobiotic Organic

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Nowadays solid waste has causing a great issue to global especially plastic waste which has slow degradation material rate. Plastic waste raises the landfill capacity and causes water pollution. According to Jabatan Pengurusan Sisa Pepejal Negara (JPSPN), there are 17,000 tonnes of municipal waste produced daily in Malaysia and 24% of the total waste is plastic waste. In statistic of JPSPN, Malaysia has 112 landfill facilities however just 6% of them are under environment control. In year 2001 until 2014, the number of landfill increases into 296. Thus JPSPN encourages the implementation of 3R concept which are reduce, reuse and recycle.

Polyethylene terephthalate (PET) is one type of plastic which is made by virgin plastic usually used to packaging of drink. In year 2012, 19 million metric tons of PET have been produced and just one of six of the total number of PET have been recycled or reused in global (The HINDU, 2014). Five of six of PET have been sent to landfill in global (The HINDU, 2014). According to Lesley McFadzean the decompose rate of a plastic bottle is 450 years. PET occupies the landfill capacity for 450 years. Thus reuse PET will reduce the capacity of landfill.

In recent years, most of the countries have taken measurement to recycle PET. In United State and Canada, National Association for PET Container Resources (NAPCOR) has been established to resolve the PET recycle problem. In 2013, NAPCOR has recycled

31.2% of PET. (Waste Management World, 2014) has stated that the demand of PET increases years by years but the recycled PET supply is still limited. PET has been reused to produce varies product such as fibre, fibrefill, carpet, strapping, food and non-food bottles, and thermoformed packaging such as cups and take-out containers. In Beijing, they have bottle-recycling vending machines to collect PET (CCTV News 2014). There is 15000 million ton of PET per years that recycled in Beijing. In Malaysia there is still lack of specific plan to treat PET. Thus this study is an alternative way to reuse PET.

In this study PET are used as an additive fibre into concrete. The flexural behaviour of addition PET into concrete has been concerned. Polymer concrete is a concrete that used polymeric material as a composite material. The flexural behaviour of polymer concrete is 3 times greater than Ordinary Portland cement (OPC) Abdel-Fattah & El-Hawary. (1999). A studied of Effect of recycled PET in the fracture mechanics of polymer mortar has shown that the flexural strength of concrete has increased as the shredded PET increase (Reis et al., 2011).

In the environment aspect, the addition of PET in concrete will reduce landfill and pollution. In economy aspect, the reuse of solid waste as material will save more money and energy. In the aspect of material structure, the strength and melting point of PET could be used to improve the strength of concrete.

Figure 1.1: PET bottle used

1.2 PROBLEM STATEMENT

Nowadays municipal waste management has been concerned about the development of country. Different measurements have been taken to save landfill capacity and environment pollution. This is especially towards plastic waste which has slow degradation rate. PET is a type of plastic that has been recycled worldwide.

In Malaysia, the municipal waste management is still poor due to the lack of technology regarding the waste's treatment and waste recycling. According to JPSPN, the waste which cannot be recycled will transfer to landfill. Landfill will affect the economy, environment and safety structure of Malaysia. JPSPN has stated that most of the landfill in Malaysia is lack of environment control. According to the JPSPN's landfill design, most of the landfill bodies will be used to build airport or road. The soil of the landfill bodies is not stable and the settlement will affect the secure of the structure of building. Landfills affect the ground water and surrounding water surface of landfill (Salem et al., 2008). Thus, reuse PET in construction will help to reduce the capacity of landfill since Malaysia is still a developing country. Figure 1.3 shows that the failure of building by using landfill bodies.

Water pollution still exists as a serious problem in Malaysia. For instance, Sungai Juru is one of the rivers which are greatly polluted by waste (Utusan, 2012). The chemical exude into the river will cause harm to the environment and health of the resident in the surrounding. The chemical included ammonia (NH_3), xenobiotic organic compounds (XOCs), dissolved organic carbon (DOC), nutrients and heavy metals (Melnyk et al., 2014). All of the chemical substances cause harm to the ecosystem surrounding, environment and health of the resident. As from the aspect of economy, recycle PET will consume more energy and money compared to reuse PET in construction. Thus, reuse PET in construction would be an alternative ways to prevent littering of PET and also save the budget of recycle PET in industrial. The Figure 1.2 shows that the water pollution of Sungai Juru.

In conclusion, reuse PET in construction will reduce the capacity of landfill and pollution problem. The particle arrangement of PET showed that it has strong and high melting point. The criteria of PET make it as a suitable material to concrete.

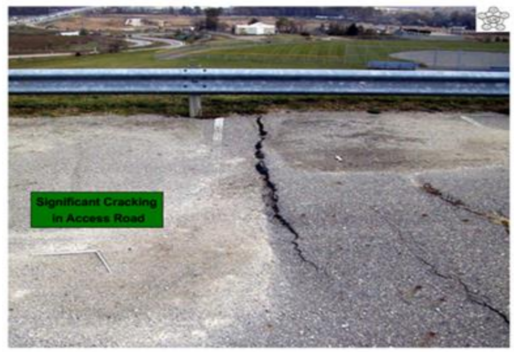

Figure1.2: Sungai Juru under pollution

Figure1.3: Road cracking built by landfill bodies

1.3 Objectives of study

Plastic waste increases dramatically, each country used different ways to solve the problem of plastic waste. The use of PET as a composite material of concrete can reduce the capacity of landfill and water pollution.

1. To determine the flexural strength of concrete which have addition of PET strip.
2. To determine the performance of different length of PET strip in concrete.
3. Compare the flexural strength of conventional and addition of PET strips concrete.

1.4 Scope of Study

In this study, different length of Polyethylene Terephthalate (PET) is added into concrete mixing.

1. The body of plastic bottle were used and shredded into the dimension of 20 mm, 40 mm and 60 mm.
2. The amount of addition of PET strips is fixed to 0.50 % of total concrete mixing.
3. The mix design of grade 25 is designed by using Polyethylene Terephthalate (PET), granite, sand, Portland cement and water.
4. The concrete size with 100 mm x 100 mm x 100 mm was casted to compressive test with the age of 28^{th} days
5. The concrete beam size with 150 mm x 200 mm x 1500 mm was casted to flexural test with the age of 28^{th} days.
6. The test involved includes flexural test, compressive test, slump test, and tensile test.

1.5 Research Significant

Reuse Polyethylene Terephthalate (PET) into concrete design bring a lot of benefits. It can reduce the capacity of waste, reduce environmental pollution, save energy of recycle PET and can be an addition fibre of concrete.

The significant of this study are:

1. Reduce the water pollution caused by PET's waste.
2. Reduce the amount of landfill capacity.
3. Reuse PET's waste as an additive fibre of concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will discuss about the literature review of flexural behaviour of Polyethylene terephthalate (PET) fibre in concrete. This chapter will discuss about the properties of PET fibre and its influence in concrete mixing. In addition, the component of concrete used and the standard of material used are stated in this chapter.

2.2 CONCRETE

Concrete is a composite material which made up with cement, water and aggregate. Quality or quantity of each material may affect the quality of concrete. The durability of concrete will affect by the permeability. Güneyisi et al. (2009) concluded that the durability reinforcement concrete is affected by the chloride due to the corrosion of steel reinforcement. Therefore, construction industrial is finding the solutions to solve the corrosion of reinforcement problem.

Generally, concrete is good in compressive but low in tensile strength. The present of micro-crack and macro-crack in concrete caused the shrinkage of concrete. The sewing effects on the crack that created by the fibre improve the tensile strength of concrete (Foti, 2013).

2.2.1 Cement

Cement is the most important material that affects the permeability of the concrete. Lower permeability of concrete can avoid chemical attack. Therefore, cement is a major contributor in the properties of concrete. The permeability of cement depends on the volume of interconnection of capillary pores in the cement paste and intensity of micro cracks at aggregate-cement paste interface as within the paste (itself) (Güneyisi et al., 2009). There are several types of cement that are common use in construction. For example Portland cement, Portland fly ash, Portland slag, Portland slag, Portland limestone, Blastfurnace and Pozzolanic. There are also several nomenclatures, specification and standard of cement tabulated on the Table 2.1 and Table 2.2.

Nowadays, cement industrial is concern about the environment impact of cement production due to the emission of carbon dioxide (CO_2). The emission of CO_2 leads to global warming as the construction development is flourishing. Addition of limestone and slag are common clinker of cement. They are new technology and cost-efficiency in reducing the emission of CO_2 into atmosphere. The cement that contains limestone has double impacts especially on the strength of the concrete and limestone can accelerate the initial cement hydration. There are certain conditions for mineral addition cement such as plasticizer. Nagrockiene et al. (2013) stated that limestone cement may affect the interaction between plasticizer and cement. Therefore, plasticizer is not suitable while combine with limestone as additive cement. Thus CEM I-type cement is recommended to use in this research.

Table 2.1: Cement type and its nomenclature.

Cement type	Nomenclature
Portland	CEM I
Portland fly ash	CEM II/A-V
	CEM II/B-V
Portland slag	CEM II/A-S
	CEM II/B-S
Portland limestone	CEM II/A-L or LL
Blastfurnace	CEM III/A
	CEM III/B
Pozzolanic	CEM IV/B (V)

Binder	Title of specification	Number
Cement	Cement Part 1: Composition, specifications and conformity criteria for common cements	BS EN 197-1
	Part 4: Composition, specifications and conformity criteria for low early strength blastfurnace cements	BS EN 197-4

Figure 2.1: The specification and the standard of cement.

2.2.2 Coarse Aggregate

There are two type of aggregate which are coarse aggregate and fine aggregate. Aggregate occupy 70%-80% of volume of concrete. The coarse aggregate occupy 2/3 of total volume of aggregate. Besides, coarse aggregate is usually greater than 4.75 mm which retained on a No. 4 sieve. Natural coarse aggregate commonly extract from pit and quarries such as granite, calcareous, basalt and marble. Aggregate absorbs the water content of total mix, thus the water cement ratio predicted is different with the water-cement ratios in experiment. The water saturation of aggregate will influence the cracking risk of concrete. Therefore, the partially saturated aggregate was subject to restrain shrinkage. Cortas et al.

(2014) suggested that aggregate affect the shrinkage of concrete. Aggregate is a porous material and it leads to shrink or swell. In addition, porosity and pores size distribution affect water saturation and the capillary tension.

Gonilho Pereira et al. (2009) concluded the aggregate mineralogy has no effect to the concrete durability properties. The size and water content of aggregate have significant effect on the durability of concrete. The increase in size of aggregate will increase the cement-aggregate interface zone. Thus, the compressive strength increases while the size aggregate decrease. The larger is the size of aggregate, the higher vacuum water absorption and air permeability. The aggregate type, size and water content during mixing will not significantly influence concrete mechanical behaviour of C30/37 concrete. Therefore, the grade of concrete is higher; the lesser is the influence of aggregate properties that affect the strength of concrete. It means the water absorption of aggregate is significant and effect of the water-cement ratio is lesser in concrete that have higher grade. Thus the size of aggregate used in concrete grade C30/37 has no effect to the strength of concrete.

Now the construction industrial has found the alternative way to reduce the use of aggregate. This is due to the increase of waste of construction and the aggregate resources are limited. Recent research found that aggregate is recyclable material in concrete component.

2.2.3 Fine Aggregate

Fine aggregate has content 0-15% in the total aggregate. Fine aggregate is used to improve the interconnection of cement-aggregate and reduces the permeability of aggregate. The size of fine aggregate is less than 4.75 mm which passing the No. 4 sieve.

According to the section 802, fine aggregate stated that the type of the fine aggregate used is depended on the specification. The several types of fine aggregate used in concrete and mortar are natural sand, manufactured sand, or blends of natural and manufactured sand. The sand used must be clean, hard, strong, durable, uncoated particle and fulfil the requirement of the specification. The sand must keep clean and free from content of others particle such as chloride ion. Chloride ion will affect the permeability, corrosion of reinforce concrete. It may affect the strength of the concrete.

2.3 POLYETHYLENE TEREPHTHALATE

Polyethylene Terephthalate (PET) is a clear tough plastic. It is commonly use as soft drink and mineral water bottle, fibrefill for pillow, sleeping bag, fibre and others. It can recycle as soft drink bottle, detergent bottles, clear film for packaging, carpet fibres, fleecy jackets and others. Besides, PET can undergo thermal reprocess and reprocessed into building panels, fence posts or fibrefill of carpet. However, this process has its limit which PET cannot undergo thermal reprocess continuously. In 2000, there was 1700,000 tons of Polyethylene Terephthalate municipal solid waste in USA (Siddique et al., 2008)

PET is a plastic resin and a type of polyester. It is a polymer product of combination of ethylene glycol and purified Terephthalic acid witnessed by the #1 code shows at the bottom of bottle (NAPCOR). Tensile strength of PET is 160 N/mm^2 (Foti, 2013). The wetting tension of PET fibre is 40 N/mm^2. PET fibre has higher alkali resistance compared with Polypropylene (PP) and Polyvinyl alcohol (PVA). PET can maintain 99% of strength after the alkali resistance test. Thus PET is high alkali resistance material; it could resist the corrosion occurs when under an alkaline environment. The non-toxic gas Carbon, Hydrogen and Oxygen were produced after combustion of PET fibre. PET fibre was used to spraying and lining of tunnels in Japan (Ochi et al, 2007)

2.4 FLEXURAL STRENGTH OF CONCRETE

Flexural strength is a measurement of strength of a concrete withstand the bending load. The experimental flexural strength can be evaluated by this formula:

$$R=\frac{PL}{bd^2}$$

R = modulus of rupture (N/mm^2)

P = maximum load carried by the specimen during testing

L = Span Length (mm)

b = average width of specimen at the fracture (mm)

d = average depth of specimen at the fracture (mm)

The alternative formula:

$$f_r = b{f_c}^n$$

f_c = compressive strength of the concrete

b = Coefficient between 0.33-0.94 (depend on the condition of concrete)

n = Coefficient either $\frac{1}{2}$ or $\frac{1}{3}$ (depend on the condition of concrete)

There are many factors affect the flexural strength of a concrete. Firstly the age of the concrete may affect the flexural strength of concrete. According to Mo et al. (2014), the strength of the concrete will increase by increases of the age of the concrete. The strength will increase until the ultimate strength has achieved. The cement content will be a manipulated variable in this case study.

2.5 FIBRE IN CONCRETE

There are many researchers studied on fibre in concrete. For example steel fibre, glass fibre, nylon fibre, carbon fibre, acrylic and others. Fibre in concrete can prevent and reduce the propagation of cracks. Fibre also affected the ductility of concrete. Kang et al. (2011) has studied about the effect of the distribution of steel fibre on flexural strength of the high strength concrete. This report stated that the length of the fibre used will affect the flexural strength of concrete. In this research, there are a few formulas discussed by Su Tae Kang.

$$\sigma_{ct} = \eta_l \eta_\Theta V_f \sigma_{fu} + V_m \sigma_{mt}$$

This equation assumed the perfect bonding between the fibre and concrete mixtures.

η_1 = coefficient related to the fibre length

η_Θ = fibre orientation coefficient

σ_{ct}, σ_{fu}, σ_{mt} = tensile strength of the composite.

$$lc = \frac{\sigma_{fu} d_f}{2\tau_{fu}}$$

l_c = fibre critical transfer length

The result of flexural test shows that the orientation and dispersion of the fibre have less influence in flexural test. In the first crack strength and flexural tensile strength, result shows that placing material is parallel to the longitudinal direction of specimen (PL-specimen). It has a higher flexural tensile strength than a steel fibre transversely to the longitudinal direction of specimen (TL specimen). In addition, the flexural test is tested on the different cutting pattern on a specimen. The tests include transversely cutting direction, horizontal cutting direction and vertical cutting direction. The result shows that the increase of number of fibre per unit area, fibre dispersion coefficient and inclined angle of fibre will increase the flexural strength of concrete.

In conclusion, the flexural behaviour of fibre is affected by the orientation of fibre. The concrete must mix equally so that the standard deviation of flexural strength can be consistent.

2.6 PLASTIC WASTE IN CONCRETE

Nowadays, research of plastic waste in concrete composite has increased. Plastic waste may use to produce plastic fibre, replacement of coarse aggregate, replacement of fine aggregate and produce polymeric concrete.

Foti. (2013) reported that recycling plastic waste reduces the amount of solid waste send to landfilling. In this case, recycled PET is used as fibres for reinforcement concrete. The tensile test of addition circular fibre into concrete by 0.5%, 0.75% and 1% PET of the weight of concrete are tested. The result showed that the 1 % of PET by weight of concrete is not suitable due to the low workability of concrete. The test on the tensile strength of different dimension of beam specimen was tested. The result showed that the higher contain of fibre produces the higher the ductile behaviour. Thus the number of fibre used increase will increase the strength of concrete. PET strips could be considered as an alternative reinforcement of concrete. The compressive strength of concrete could be use as structural concrete. Meanwhile, the ductility of concrete has improved.

Siddique et al. (2008) shows the detail review about the waste and recycled plastic in construction, discuss the results of researches which have been published and waste management options. This research shows that post-consumer plastic aggregate can replace conventional aggregate. The compressive strength decreases while the percentage of plastic aggregate used increases. Splitting tensile has same condition with compressive strength. In the same research, the use of PET resin as polymer concrete is suitable to use in precast application as it can reach more than 80% of ultimate strength of concrete in 1 day. PET resin in mortar produces a good quality mortar. Polypropylene fibres improve impact resistance of concrete and increase the permeability of concrete. The potential of plastic waste in concrete is high as shown by the result of various tests which have been carried out. The different types of plastic may have different aspects on concrete material behaviour. Thus, recycled plastics in concrete showed the future trends of concrete material.

In conclusion, plastic waste in concrete material is a high potency research. It brings benefit on different aspects. In structure aspect, it achieves an idealize properties and result. The used of recycle plastic is still improving by research methodology.

2.7 FLEXURAL BEHAVIOUR OF ADDITION PET IN CONCRETE

Saikia & de Brito. (2014) studied the flexural strength decreases while the quantities of plastic aggregate increase. This study tends to investigate the suitability of shredded PET bottle as a partial substitution of natural aggregate. The result shows that the compressive strength and flexural strength decreases while the fraction of shredded plastic aggregate