ENGINEERING PROPERTIES OF RING SHAPED POLYTHEYLENE TEREPHTHALATE (RPET) FIBER SELF-COMPACTING CONCRETE

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Specially dedicated to my beloved mother,

Amna Shaikh Salleh,

To my loving siblings, Siti Faezah Sheikh Khalid, Sheikh Mohd Fauzi Sheikh Khalid, Sheikh Munir Sheikh Khalid, Siti Faradinah Sheikh Khalid, &

Siti Faradibah Sheikh Khalid,

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Who are always there when I need them.

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ABSTRACT

Polyethylene terephthalate (PET) bottles are plastic containers that are typically discarded, and thus, cause environmental pollution. To solve this problem, PET bottles are recycled in concrete. Previous studies have mostly used PET with straight or irregularly shaped fibers. It has been shown that PET has a weak interfacial bond with cement paste in the pullout load because of the lamellar shape of fibers. Therefore, ringshaped PET (RPET) fibers are introduced in this study to overcome the limitations of traditional straight, lamellar, or irregularly shaped fibers. RPET fibers are mainly designed with a special shape to mobilize fiber yielding rather than fiber pullout. RPET fibers are made directly from waste bottles. The diameter of RPET bottles is fixed at $60 \pm$ 5 mm. The width of RPET fibers is fixed at 5, 7.5, or 10 mm and designated as RPET-5, RPET-7.5, and RPET-10 respectively. This study mainly determines the optimum waterbinder ratio and fiber content of RPET fiber concrete (FC) through self-compacting, as well as through compressive, tensile, and toughness strength tests. A water-binder ratio of 0.55 and working ranges from 0.25% to 1% of fiber content are successfully accepted for all sizes of RPET fibers. Result of the pullout test shows that RPET fiber interfacial bond strength ranges from 0.502 MPa to 0.519 MPa for RPET-5 fiber, from 0.507 MPa to 0.529 MPa for RPET-7.5 fiber, and from 0.516 MPa to 0.540 MPa for RPET-10 fiber. This study presented that the compressive and tensile strength of RPET fiber exhibited an increase of 17.3% and 35.7%, respectively compared to normal concrete. RPET FC shows improvement in first crack load for flexural toughness strength of RPET FC with increase of 24.5% compared to normal concrete specimen. Moreover, 156 FC cylinders were used to develop new equations for predicting the compressive and tensile strengths of RPET FC via multiple regression analysis. Two equations are obtained. These equations are included in calculating compressive and tensile strength of RPET FC limited up to 28 days In conclusion, incorporating RPET fibers when recycling waste PET bottles in concrete produces FC with An improvement performance comparable to that of normal concrete.



ABSTRAK

Polyethylene Terephthalates (PET) botol merupakan sebahagian dalam produk plastik yang telah dibuang terus dan meyebabkan pencemaran kepada alam sekitar. Sehubungan dengan itu, salah satu cara untuk mengatasi masalah ini adalah dengan mengitar semula di dalam bentuk *fiber*. Kajian terdahulu menjurus kepada bentuk lurus atau bentuk tidak seragam. Rumusan kajian terdahulu menunjukkan bentuk lurus and bentuk tidak seragam PET fiber di dalam konkrit mempunyai kelemahan dari segi kekuatan ikatan permukaan antara fiber dan konkrit semasa ujian penarikan fiber. Oleh itu, bagi mengatasi masalah ini bentuk bulatan PET atau di pangil sebagai Ring shaped PET (RPET) di perkenalkan di dalam kajian ini. RPET fiber dapat menahan kesan pernarikan fiber dan mengalami kegagalan pada kekuatan tegangan maksimum *fiber* itu sendiri. *RPET fiber* dihasilkan secara terus dari botol kitar semula. Ia mempunyai diameter bersaiz 60 ± 5 mm. Kelebaran RPET fiber terbahagi kepada tiga iaitu 5 mm, 7.5 mm, dan 10 mm yang bermaksud kepada RPET-5, RPET-7.5, dan RPET-10. Objektif utama kajian ini adalah menentukan kesesuain dalam nisbah air-simen dan kandungan fiber melalui ujian seperti anti pemadatan konkrit, kekuatan mampatan, kekuatan tegangan, kekuatan keutuhan konkrit fiber itu sendiri. Di akhir ujian menunjukkan 0.55 nisbah air-simen dan kandungan effektif sebanyak 0.25% hingga 1.00% adalah terbaik untuk semua saiz RPET fiber. Keputusan ujian penarikan daya ikatan permukaan RPET fiber adalah sebanyak 0.502 MPa hingga 0.519 MPa, 0.507 MPa hingga 0.529 MPa, dan 0.516 MPa hingga 0.540 MPa untuk *RPET-5*, *RPET-7.5*, dan *RPET-10 fiber*. Kajian ini menunjukkan peningkatan sebanyak 17.3% sehingga 35.7% untuk ujian kekuatan mamapatan dan ujian ketegangan dibandingkan dengan spesimen normal konkrit. Malahan, RPET fiber konkrit memberi peningkatan sebanyak 24.5% untuk kekuatan rekahan pertama setelah dibandingkan dengan normal konkrit spesimen. Kemudian, 156 silinder konkrit melalui ujian kekuatan mampatan dan tegangan diambil serta dianalisa untuk menghasilkan formula baru melalui keadah Multiple Regression. Dua formula ini dapat menentukan secara teori bagi kekuatan mampatan dan tegangan fiber konkrit, namun terhad sehingga tempoh matang konkrit 28 hari sahaja. Akhir kata, campuran RPET fiber dengan konkrit adalah berkesan dalam penghasilan *fiber* konkrit setelah dibandingkan dengan konkrit normal.

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LIST OF SYMBOLS AND ABBREVIATIONS

ø diameter constant κ stress of specimen σ concrete strain Ecc D_f thickness of PET fiber $E_{\mathcal{C}}$ Modulus of Elasticity (MOE) UN AMINA compressive strength (Eurocode) fck compressive strength (British Standard) fcu tensile strength fct flexural tensile strength fct,fl splitting tensile strength fct,sp fr modulus rupture of concrete first crack loading by UNI 11039-2 fIf G_{f} fracture energy h_b height of specimen in flexural tensile strength Lf length of PET fiber first crack loading by UNI 11039-2 Plf V_f volume fraction of PET fibers ACI American Concrete Institute ASTM American Standard Test Method _ BS **British Standard** _ CPET **Crystalline PET** _ EG Ethylene glycol _ European Standard EN conventional fiber factor F

FA		Fly ash
FRC	-	Fiber Reinforced Concrete
HDPE		High Density Polyethylene
ILSI	-	International Life Science Institute
ISIS	-	Intelligent Sensing for Innovative Structures
LB	-	L-box
LVDT	-	Liner Variable Differential Transformer
MC	-	Moisture content
MPMA	-	Malaysian Plastic Industry
MSE	-	Mean square residual or error
MSR	-	Mean square regression
MSW	-	Municipal Solid Waste
PA	-	passing ability
PET	-	Polyethylene Terephthalate
PP		Polypropylene
RC	-	Reinforced Concrete
UTF	-	Universal Test Frame
UTM		Universal Test Machine
UTHM	TD	Universiti Tun Hussein Onn Malaysia
SCC	$\sum_{i=1}^{n}$	Self-compacting concrete
SF	-	Slump flow
SPSS	-	statistical analysis in social science
TPA	-	Terephthalic acid
PTA	-	Pure Terephthalic acid
VF	-	Flow rate

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CHAPTER 1

INTRODUCTION

1.1. Background of study



The rapid development of the construction industry has increased the demand for tall and long-span concrete structures and the attempt to satisfy this demand with fiber concrete (FC) (Ashour *et al.*, 1992). Fibers are primarily used as replacements for conventional reinforcement in non-structural applications to control early thermal contraction and drying shrinkage cracking. These benefits have increased the application of fibers in structures, particularly those with low reliability levels, such as slabs on grade, foundations, and walls. The use of fibers as a part of the overall structural design of structural applications is continuously increasing. Fibers are added to improve the fracture characteristics and behavior of structures through the capability of the fibers to bridge cracks. Therefore, many studies have been extended to analyze various fiber types and shapes, particularly in investigating the performance of concrete reinforced with fibers (Ochi *et al.* 2007, Kim *et al.* 2010, Foti, 2011 & Fraternalli *et. al.* 2011). The possibility of using waste materials as fibers to be incorporated in concrete has been determined. Adding waste fibers has good effects on the properties of the final products and benefits the environment.

Waste polyethylene terephthalate (PET) bottles can be used in various applications such in construction. The development of new construction materials using recycled PET fibers is important in the construction and PET recycling industries.

In the field of civil engineering research, the recycled PET has begun to be adopted in the concrete. Studies have incorporated PET waste into concrete (Ochi *et al.* 2007, Pereire *et al.* 2011, Foti, 2012, & Irwan *et al.* 2013). These studies have shown that recycled PET fibers produce different results depending on their shape and content. An example of study that has been conducted by Ochi *et al.* (2007) revealed that using 30 mm-long PET fibers can increase tensile strength for volume replacement up to 1.5% compared with that made of 20 mm-long fibers. They claimed that long fibers have the capability to interlocking fiber bridges in concrete because fibers can be inserted between aggregates compared with 20 mm-long fibers. However, recycled PET fibers exhibit limited performance because of the weak interfacial bond strength of PET surface during fiber bridge stress, particularly in fibers with lamellar and irregular shapes (Fratenali *et al.*, 2010 & Irwan *et al.*, 2014).

Therefore, traditional straight, lamellar, or irregularly shaped fibers have limitations in providing significant results for engineering properties. Thus, this study produces ring-shaped PET (RPET) fibers and investigates the possibility of incorporating them into concrete. Optimum fiber content needs to be determined, and the performance of recycled PET FC need to be investigated.

1.2 Statement of problem

The amounts of plastic consumed annually have been increasing steadily. Therefore, selecting PET waste products as recycled materials is appropriate from the perspective of civil engineering applications. Recycled PET may be used as fiber reinforcement for structural concrete. Fiber-reinforced concrete (FRC) can enhance crack control and ductility in quasi-brittle concrete and can be an alternative for mass consumption, which is an important issue in recycling waste materials (Kim *et al.*, 2008). Major studies using PET bottles with different sizes, shapes, fiber contents, and mix concrete water–cement ratios have been performed, as shown in Figure 1.1.



- Use irregular shape of PET fiber incorporated with concrete,
- Use PET volume ranged of 0.5% to 1.50% fiber content,
- Have a slightly increase in compressive strength. It shows an exhibited improvement strength on tensile and first crack ductility compared to normal concrete, and
- PET FC made of self-compacting concrete (SCC) mixture exhibited improvement on filling and passing capability compared PET FC (without SCC).

Figure 1.1: Previous studies on waste PET in concrete

Ochi *et al.* (2007) studied recycled PET bottles with 30 mm-long fibers. The fiber surface was indented to provide sufficient friction energy. The authors claimed that a high percentage of fiber content produced fiber bundles during mixing and pouring. Binder material and superplasticizer help fiber distribute well in concrete compared normal concrete (without binder and superplasticizer). The results of previous studies have shown that PET has a weak interfacial bond with cement paste in the pull-out load because of the lamellar shape of fibers (Pelliser *et al.*, 2012). Pelliser *et al.* (2012) claimed that lamellar-shaped PET fibers exhibit limited performance in PET FC.

Ramadevi *et al.* (2012) exhibited that compressive strength increased up to 2% replacement content of waste PET fibers. An increase in fiber content increases concrete strength. Foti (2012) studied the possibility of using fibers from PET bottles to increase concrete ductility. Foti (2012) claimed that ring PET fibers exhibit impressive performance compared with lamellar-shaped PET fibers, particularly in tensile strength. The ring shape is the main factor that contributes to fiber bridges during tensile stress. Irwan *et al.* (2013) used a waste bottle with irregularly shaped PET fibers. The authors claimed that concrete mixture is not the only factor that contributes to the improvement of the compressive strength of FC. Fiber size and shape also have roles to prevent slip out fiber at high stress load and exhibited fiber concrete (FC) performance.



To overcome the limitations of traditional straight or irregularly shaped fibers, ring-shaped fibers were selected in this study. Ring-shaped fibers are mainly designed to mobilize fiber yielding (rupture by tensile) rather than fiber pullout (slipped by fiber force), which is a primary advantage over straight or irregularly shaped PET fibers as per discussed in Foti, 2011. The more number of fibers in concrete that will increase fiber interlocking mechanism between fiber and matrix concrete is needed. Besides, PET fiber made of SCC mixture exhibited sufficient result on workability and strength concrete compared to PET fiber without SCC mixture. Therefore, this study aimed to prove the advantage of ring-shaped PET fiber in terms of fresh and hardened-state of RPET FC on mixture design according to self-compacting concrete (SCC).

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