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,

Thank you for your prayers, sacrifices, patience, understanding and being the ones who lift me up every time I fall down.

Also to my beloved friends, Muhamad Asyraf Roslan, Mohd Khairil Annas Mohamad, Mohd Zainuri Mohd Hatta, Amirul Imran Abu Kasim, Mohd Reeza Hilmi, & Azreen Makalis

Who are always there when I need them.

Thank you for your support.

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Thanks for your precious guideline

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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, ring-shaped 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 ± 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 water–binder 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.

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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 fibe*r. 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

ϕ - diameter

κ - constant

σ - stress of specimen

ε_{cc} - concrete strain

D_f - thickness of PET fiber

E_c - Modulus of Elasticity (MOE)

f_{ck} - compressive strength (Eurocode)

f_{cu} - compressive strength (British Standard)

f_{ct} - tensile strength

$f_{ct,fl}$ - flexural tensile strength

$f_{ct,sp}$ - splitting tensile strength

f_r - modulus rupture of concrete

f_{If} - first crack loading by UNI 11039-2

G_f fracture energy

h_b - height of specimen in flexural tensile strength

L_f - length of PET fiber

P_{If} - first crack loading by UNI 11039-2

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

EN - European Standard
F - conventional fiber factor

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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	-	Universiti Tun Hussein Onn Malaysia
SCC	-	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.

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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.

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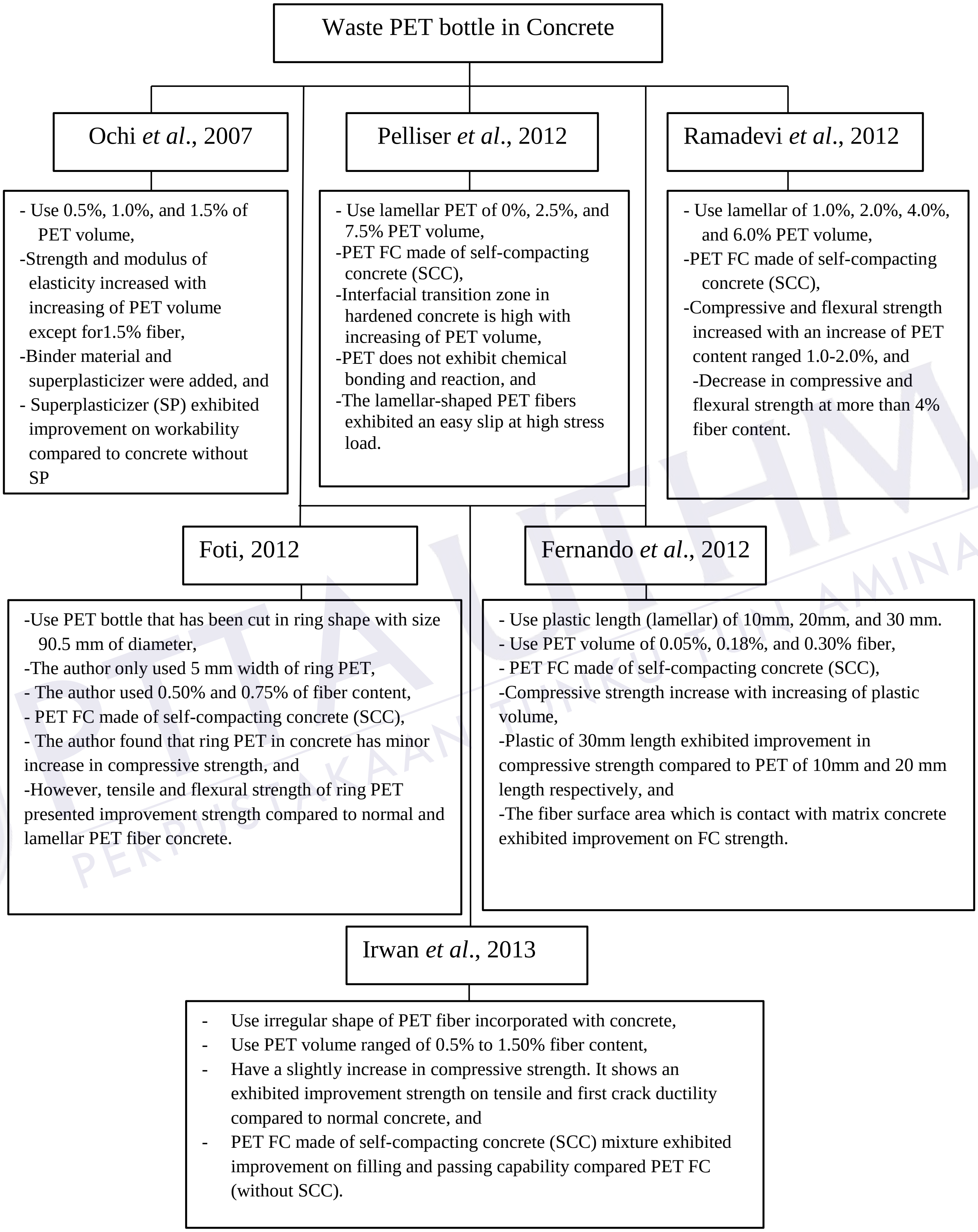
1.2 Statement of problem

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.



Waste PET bottle in Concrete

Ochi *et al*., 2007

- Use 0.5%, 1.0%, and 1.5% of PET volume,
-Strength and modulus of elasticity increased with increasing of PET volume except for1.5% fiber,
-Binder material and superplasticizer were added, and
- Superplasticizer (SP) exhibited improvement on workability compared to concrete without SP

Pelliser *et al*., 2012

- Use lamellar PET of 0%, 2.5%, and 7.5% PET volume,
-PET FC made of self-compacting concrete (SCC),
-Interfacial transition zone in hardened concrete is high with increasing of PET volume,
-PET does not exhibit chemical bonding and reaction, and
-The lamellar-shaped PET fibers exhibited an easy slip at high stress load.

Ramadevi *et al*., 2012

- Use lamellar of 1.0%, 2.0%, 4.0%, and 6.0% PET volume,
-PET FC made of self-compacting concrete (SCC),
-Compressive and flexural strength increased with an increase of PET content ranged 1.0-2.0%, and
-Decrease in compressive and flexural strength at more than 4% fiber content.

Foti, 2012

-Use PET bottle that has been cut in ring shape with size 90.5 mm of diameter,
-The author only used 5 mm width of ring PET,
- The author used 0.50% and 0.75% of fiber content,
- PET FC made of self-compacting concrete (SCC),
- The author found that ring PET in concrete has minor increase in compressive strength, and
-However, tensile and flexural strength of ring PET presented improvement strength compared to normal and lamellar PET fiber concrete.

Fernando *et al*., 2012

- Use plastic length (lamellar) of 10mm, 20mm, and 30 mm.
- Use PET volume of 0.05%, 0.18%, and 0.30% fiber,
- PET FC made of self-compacting concrete (SCC),
-Compressive strength increase with increasing of plastic volume,
-Plastic of 30mm length exhibited improvement in compressive strength compared to PET of 10mm and 20 mm length respectively, and
-The fiber surface area which is contact with matrix concrete exhibited improvement on FC strength.

Irwan *et al*., 2013

- 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

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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).

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

REFERENCES

Abdul K. (2007). Self -compatibility of high volume hybrid fiber reinforced concrete. *Construction and Building Materials*, 21 (2007). pp. 1149–1154.

ACI Committee 237R. (2007). ACI 237R-07. Self-consolidating concrete (ACI 237R-07). American Concrete Institute (ACI), Farmington Hills Mich., United State of America (USA), pp. 30.

ACI Committee 318. (1995). ACI 318-95. Building code requirements for structural concrete (ACI-318-05) and commentary (ACI 318R-95). American Concrete Institute (ACI), Farmington Hills Mich., United State of America (USA), pp. 430.

ACI Committee 363. (2006). ACI 363.1R-06. State-of-the art report on high strength concrete. *American Concrete Institute (ACI)*. Farmington Hills, MI: United State of America (USA).

ACI Committee 440. (2006). ACI 440.1R-06. Guide for the design and construction of concrete reinforced with FRP bars. *American Concrete Institute (ACI)*, Farmington Hills Mich., United State of America (USA), pp. 45.

Ackay, B. & Tasdemir, M. A. (2012). Mechanical behaviour and fibre dispersion of hybrid steel fibre reinforced self-compacting concrete. *Construction and Building Materials*, 28 (2012). pp. 287-293.

Agamuthu P. & Faizura P.N. (2005). Biodegradability of Degradable Plastic Waste. *Waste management*, 23(2), pp. 95-100.

Ahmad, M. di Prisco, C. Meyer, G.A. Plizzari, & S. Shah. (2004). International Workshop on Advances in Fiber Reinforced Concrete, Bergamo, Italy. 24-25. pp. 135-148.

Ahmed S. F. U, Maelaj M. & Paramasiam P. (2007). Flexural response of hybrid steel-polythylene fiber reinforced cement composites containing high volume fly ash. *Construction and Building Materials*, 21(2007). pp 1088-1097.

PTTAUTHM PERPUSTAKAAN TUNKU TUN AMINAH

Al-Manaseer, A.A., Dalal, T.R. (1997). Concrete Containing Plastic Aggregates. *Concrete International*, 19(8), pp. 47–52.

Alavi Nia A., Hedayantian M., & Nili M., & Sabet V. A. (2012). An experimental and numerical study on how steel and polypropylene fibers affect the impact resistance in fibre-reinforced concrete. *International Journal of Impact Engineering.* 46 (2012). pp. 62-73.

Albano C, Camacho N, Hernandez M, & Gutierrez A. (2009). Influence of Content and Particle Size of Waste Pet Bottles on Concrete Behaviour at Different W/C Ratios. *Waste Management*, 29 (2009), pp. 2707–2716

Alberti M. G., Enfadaque A., & Galvez J. C. (2014). On the mechanical properties and fracture behavior of polyolefin fiber-reinforced self-compacting concrete. *Construction and Building Materials,* 55 (2014), pp. 274-288.

Ali M., Xioyang Li, & Nawawi chuow (2013). Experimental investigations on bond strength between coconut fibre and concrete. *Material & Design*, (2013). pp. 596-605.

Alvarez, M., Salas, J. & Veras, J. (1988). Properties of Concrete Made with Fly Ash. *The International Journal of Cement Composites and Lightweight Concrete,* 10(2), pp. 109-120.

Ashour, S. A., Hasanain, G. S. & Wafa, F. F. (1992). Shear Behaviour of High- Strength Fiber Reinforced Concrete Beams. *American Concrete Structure Structural Journal*, March-April (1992), pp. 176-184

ASTM C1611-05. Standard test method for slump for of self-compacting concrete. *The American Society for Testing and Materials Standard*, USA.

ASTM C469 / C469M - 10 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. *The American Society for Testing and Materials Standard*, USA.

ASTM C 469-87a. Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression. *The American Society for Testing and Materials Standard*, USA.

ASTM C-494 Type A & F. Standard Specification for Chemical Admixtures for Concrete**.** *The American Society for Testing and Materials Standard*, USA.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

ASTM C618-03. Standard Specification for Fly Ash and Raw Calcined Natural Pozzolan for Use as Mineral Admixture in Portland Cement Concrete. *The American Society for Testing and Materials Standard* (ASTM), USA

ASTM D638-10.Standard test method for tensile properties of plastic. *The American Society for Testing and Materials Standard* (ASTM), West Conshohocken, Pennsylvania, USA

ASTM C1018-97. Standard test method for flexural toughness and first crack load strength of fiber reinforced concrete, *The American Society for Testing and Materials Standard* (ASTM), West Conshohocken, Pennsylvania, USA

B.W. Jo, S. K. Park, & C. H. Kim. (2006). Mechanical Properties of Polyester Polymer Concrete Using Recycled Polyethylene Terephthalate. *ACI Structural Journal*, 103(2), pp. 219– 225

Barros, J., Pereira, E., Ribeiro, A., Chuna, V., & Antunes, J. (2004). Self-Compacting Steel Fibre Reinforced Concrete for Precasted Sandwich Panels – Experiments and Numerical Research. Fibre Reinforced Concrete from Theory to Practice

Bataneyh M., Marie I., & Asi (2007). Use of selected waste material in concrete mixes. *Waste Management*. 27 (2007), pp. 1870-1876.

Benaicha, M., Jalbaud, O., Hafidi, A. A., & Burtschell, Y. (2013). Rheological and mechanical characterization of fibre reinforced self-compacting concrete *International Journal of Engineering and Innovation Technology*, 2 (2013). pp. 2277-3754

Bilodeau, A. & Malhotra, V. M. (2000). High-Volume Fly Ash System in Concrete Solution for Sustainable Development. *ACI Materials Journal*,pp. 41-50

Borosnyói, A. (2002). Serviceability of CFRP prestressed concrete beams. Doctor of Philosophy (PhD) Thesis, Budapest University of Technology and Economics. Faculty of Civil Engineering, Budapest, Hungary

British Standard Institution. (2009). Eurocode 2: Design of concrete structures: EN 12350 - 1:2009: Testing fresh concrete: Sampling: British standard. London: BSi.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

British Standard Institution. (2000). Eurocode 2: Design of concrete structures: EN 12390 - 3:2000: Testing hardened concrete: Compressive strength for test specimens: British standard. London: BSi.

British Standard Institution. (2000). Eurocode 2: Design of concrete structures: EN 12390 - 6:2000: Testing of hardened concrete: Tensile strength test: British standard. London: BSi.

British Standard Institution. (1997). Eurocode 2. Design of concrete structures - Part I: General rules and rules for buildings. British standard. London: BSi.

British Standard Institution. (1983). British Standard: Testing concrete: BS 1881 - 121:1983: Method for determination of static modulus of elasticity in compression: British standard. London: BSi.

Carino, N.J., and H.S.Lew, 1982. Re-examination of the Relation between Splitting Tensile and Compressive Strength of Normal Weight Concrete. *Journal of American Concrete Institute,* 79(3), May-June (1982). pp. 214-219.

Carrasquillo, R. L., Slate F. O., Nilson, & A. H. (2003). Microcracking and Behaviour of High Strength Concrete Subjected to Short Term Loading", *ACI Materials Journal*, 78(3), pp. 179-186.

CEB-FIP Model Code. Model code for concrete structures. Comite Euro-International due Beton/Federation Internationale de la Precontrainte, Paris; 1990

CEN. (1992). "Eurocode 2: Design of concrete structures - Part 1.1: General rules and rules for buildings (EN 1992-1-1:1992)." Comité Europeen De Normalisation, Brussels, pp.195.

CEN. (2004). "Eurocode 2: Design of concrete structures - Part 1.1: General rules and rules for buildings (EN 1992-1-1:2004)." Comité Europeen De Normalisation, Brussels, pp. 225.

Chawla, &Y.L. Shen. (2001). Mechanical Behavior of Particle Reinforced Metal Matrix Composites. *Advanced Engineering Materials,* 3(6), pp. 357-360.

Choi O. C. & Lee C. (2003). Flexural performance of ring type steel fibre reinforced concrete. *Cement and Concrete Research*, 33(2003). pp 841-849.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Choi Y.W, Moon D., J. S. Chung, & S. K. Cho. (2005). Effects of Waste PET Bottles Aggregate on the Properties of Concrete. *Cement and Concrete Research*, 35(4), pp. 776–781.

Choi Y. W., Moon D, Kim Y, & Lachemi M. (2009). Characteristics of Mortar and Concrete Containing Fine Aggregate Manufactured From Recycled Waste Polyethylene Terephthalate Bottles. *Construction Building Material*. 23 (2009), 2829–35.

CPH. (2008). "Instrucción de Hormigón Estructural EHE-08." Comisión Permanente Del Hormigón. Ministerio De Fomento, Madrid (Spain), pp. 722.

Deepa S. Shri, R. Thenmozhi, & M. Anitha. (2012). Mechanical properties of SCC with polypropylene fibres. *Advanced Scientific Reseach & Technology*, Vol. 2, No.3 (2012), pp. 375-388.

Dong, J., Wang, Q. & Guan, Z. (2012). Structural behaviour of RC beams with external flexural and flexural-shear strengthening by FRP sheets. Composites: Part B 44 (2012). pp. 604-612.

Dossland, (2008). Fibre Reinforcement in Load Carrying Concrete Structures. Doctor of Philosophy (PhD) Thesis. Norwegian University of Science and Technology, Norway (NTNU).

Doughlas R. (2004). Properties of self-compacting concrete containing type F fly ash. Master of Applied Science Thesis, Northwestern University, USA.

EFNARC. (2002). “Specification and guidelines for self-compacting concrete”. *European Federation of Supplies of Specialist Construction Chemicals*, Farnham, Surrey, UK.

Eurocede 2: 1992-1-1:2004. Design of Concrete structures. *European Standard*, London

European Commission DG ENV: 2011. Plastic Waste in the Environment, *Institute European Environmental Policy*, France

Fantilli, A.P., Ferretti, D., and Rosati, G. (2005). Effect of Bar Diameter on the Behavior of Lightly Reinforced Concrete Beams. *Journal of Materials in Civil Engineering*, 17(1), pp. 10-18.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Ferrara L., Yong Dork P., & Shah Surendra P. (2007). A method for mix design of fiber reinforced self-compacting concrete. *Cement and Concrete Research*, 37, pp. 957-971.

Fischer, G. and V. Li (2006). Effect of Fiber Reinforcement on the Response of Structural Members. Engineering Fracture Mechanics, 74. pp. 258-272.

Foti D. (2011). Preliminary Analysis of Concrete Reinforced With Waste Bottles PET Fibers. *Construction and Building Materials*, 25, pp. 1906-1915.

Foti D. (2012). Use of recycled waste PET bottles fibers for the reinforcement of concrete. *Composite Structure*.

Fraternali A., Ciancia V., Chechile R., Rizzano G (2011). Experimental Study of Thermo-Mechanical Properties of Recycled PET Fiber-Reinforced Concrete. *Composites Structures*, 93, pp. 2368-2374.

Frigione M. (2010). Recycling of PET Bottles as Fine Aggregates in Concrete. *Waste Management*. 110(2), pp. 31-35.

Grace, N. F., Soliman, A. K., Abdel-Sayed, G. & Sale, K. R. (1998). Behaviour and Ductility of Simple and Continuos FRP Reinforced Beams. *Journals of Composites for Construction*. 2 (1998), pp. 149-203.

Grunewald S. & Walvaren (2010). Maximum fiber content and passing ability of self-compacting fibre reinforced concrete. *American Concrete Institution*. 274(2), pp. 15-30.

Guo, Z.h. & Zhang X. (1999). Investigation of Complete Stress-Deformation Curves for Concrete in Tension. *ACI Materials Journal*, 84(5), pp. 278- 285.

Hassan M.J., Afroz M., & Mahmud H.M.I. (2011). An experimental investigation on mechanical behavior macro synthetic fiber reinforced concrete. *International Journal of Civil & Environmental Engineering.* 11(3), pp. 18-23.

Irwan J.M., N. Othman, H.B.Koh, R.M. Asyraf, S.K. Faisal, & M.M.K. Annas, (2013) the Mechanical Properties of PET Fiber Reinforced Concrete from Recycled Bottle Wastes, *Advanced Materials Research*, Vol. 795, pp. 347-351.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Irwan J.M, N. Othman, H.B. Koh, R.M. Asyraf, Faisal S.K, & M.M.K. Annas, (2014). Maximum crack spacing model for irregular -shaped polyethylene terephthalate fibre reinforced concrete beam. *Advances in Civil, Structural, Environmental & Bio-Technology,* CSEB 2014.

ISIS Canada. (2001). Reinforcing concrete structures with fiber reinforced polymers - Design manual No. 3. ISIS Canada Corporation. University of Manitoba, Manitoba, Canada, pp. 158

Jaturapitakkul, C., Kiattikomol, K., Tangchirapat, W. & Saeting, T. (2004). Use of Ground Coarse Fly Ash as a Replacement of Condensed Silica Fume in Producing High Strength Concrete. *Cement and Concrete Research*, 34, pp. 549-555.

Jee, N.Y. Sangchun & Hongbum (2004). Prediction of compressive strength of in situ concrete based on mixture proportions. *Asian Architect Building Engineering*, 3, pp. 9-16.

Jo B, Park S, & Park J. (2008). Mechanical Properties of Polymer Concrete Made With Recycled PET and Recycled Concrete Aggregates. *Construction Building Material,* 22, 2281–91.

Khayat, K. H. (2000). Optimization and performance of air-entrained, self-consolidating concrete. *ACI Materials Journal*, Vol. 97, No. 5, pp. 526-535.

Khedar, G.F., A.M. Al-Gabban & M.A. Suhad (2003). Mathematical model for prediction of cement compressive strength at the ages of 7 and 28 days within 24 hours. *Material structures,* 36 (2003). pp. 693-701.

Khunthongkeaw, J., Tangtermsirikul, S. & Leelawat, T. (2006). A study on carbonation depth prediction for fly ash concrete. *Construction and Building Materials*, 20(9), pp. 744-753

Kim (2010). Material and Structural Performance Evaluation of Recycled PET Fiber Reinforced Concrete. *Cement & Concrete Composites,* 32, pp. 232-240.

Kim, H. S. & Shin, Y. S. (2011). Flexural behaviour of reinforced concrete (RC) beams retrofitted with hybrid fiber reinforced polymers (FRPs) under sustaining loads. *Composites Structures*. 93 (2011). pp. 802-811.

Légeron, F., Paultre, P. (2000). Prediction of Modulus of Rupture of Concrete. *ACI Materials Journal*, 97(2), pp. 193-200.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Li, Q. & Ansari, F. (2000). High-Strength Concrete in Uniaxial Tension. *ACI Materials Journal*, 97(1), pp. 49-57.

Li (2011). Investigate in quality control of fiber reinforced self-compacting concrete during construction", 2nd International Conference on Construction and Project Management, Vol. 15, Singapore.

Liao W., Chao S., & Naaman A. (2010). Experience sith self-consolidating high performance fibre reinforced mortar and concrete. *American Concrete Institution*. 274 (6), pp. 79-94

Lohtia, R. P. & Joshi, R. C. (1995). Mineral Admixtures. *Concrete Admixtures Handbook, Properties, Science, and Technology Second Edition*, New Jersey, USA: Noyes Publications.

Lyslo. A. (2008). Fibre Reinforcement in Load Carrying Concrete Structures. Doctor of Philosophy (PhD) Thesis, Norweigian University of Science and Technology, Norway.

Mahdi F, Abbas H, Khan A. Strength characteristic of poymer mortar and concrete using different compositions of resins derived from post-consumer PET bottle. *Construction Building Material*, 2010; 24:25-36

Majdzadeh F. (2003). Fracture toughness of hybrid fibre reinforced self-compacting concrete, Master Thesis of University of British Columbia.

Malaysian Plastic Forum (2007). Plastic: Safety and Health. *Malaysian Plastics Manufacturers Association (MPMA):* Malaysia.

Marzouk, H., Chen, & Z. W. (1995). Fracture Energy and Tension Properties of High-Strength Concrete. *Journal of Materials in Civil Engineering*, 7(2), pp. 108- 116.

Marzouk O, Dheilly R, & Queneudec M. (2007). Valorization of Post-Consumer Waste Plastic in Cementitious Concrete Composites. *Waste Management*, 27. pp. 310–318.

Mazaherpour, H., Gahnbarpour, S., Mirmoradi, S. H., & Hosseinpour, I. (2011). The effect of polypropylene fibres on the properties of fresh and hardened lightweight self-compacting concrete. *Construction and Building Materials*, 25 (2011). pp. 351-358.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Mehta, P. K., & Monteiro, P. J. M. (2006). Concrete – Microstructure, Properties and Materials. 3rd ed. United States of America: McGraw Hill.

Mindness, S., Young, J. F. & Darwin, D. (2003). Concrete. 2nd edition. United States of America: Prentice Hall.

Minelli, F. (2005). Plain and Fibre reinforced concrete beam under shear loading. Doctor of Philosophy (PhD) Thesis, Department of Civil Engineering, University of Brescia, Italy.

Mirmiran, A. E., Shahawy, M. & Samaan, M. (1999). Strength and Ductility of Hybrid FRP-Concrete Beam-Columns. *Journals of Structural Engineering*. Vol 125, pp 1085-1093.

Mohamed, H. M. & Masmoudi, R. (2010). Flexural strength and behaviour of steel and FRP-reinforced concrete-filled FRP tube beam. *Engineering Structures*, 32 (2010). pp. 3789-3800.

MS 522. (2007). Specification for Portland cement composites. *Malaysian Standard*, Malaysia.

Mustafa (2007). Hybrid fiber reinforced self-compacting concrete with a high volume coarse fly ash. *Construction and Building Materials*, 21, pp. 150–156.

Nawy, E. G. (1996). Fundamentals of High Strength High Performance Concrete. London, UK: Longman Group Limited.

Neville, A. M., & Brooks, J. J. (2010). Concrete Technology. 2nd edition. United Kingdom: Longman.

Nili Mahmoud & Afraoughsabet V. (2010). The effects of silica fume and polypropylene fibers on the impact resistance and mechanical properties of concrete. *Construction and Building Materials*, 24. pp. 927-933.

Ochi, T., Okubo, S. & Fukui, K. (2007). Development of Recycled PET Fiber and Its Application as Concrete- reinforcing Fiber. *Cement & Concrete Composites*, 29 (2007). pp. 448-455.

Okamura H. (1997). Self-compacting high performance concrete. *Concrete International*, 19(7), pp. 2103-2112

Oliveira, L. A. P. D., & Gomes, J. P. C. (2011). Physical and mechanical behaviour of recycled PET fibre reinforced mortar. *Construction and Building Materials*. 25 (2011). pp. 1712-1717.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Oner, A., Akyuz, S. & Yildiz, R. (2005). An Experimental Study on Strength Development of Concrete Containing Fly Ash and Optimum Usage of Fly Ash in Concrete. *Cement and Concrete Research*, 35, pp. 1165– 1171.

Pacheco F.Torgal., Yining Ding, & Said Jalali (2012). Properties and durability of concrete containing polymetric wastes (tyre rubber and polyethylene terephthalate bottles). *Construction and Building Materials*, 30, pp. 714-724.

Packaging Materials Report (2000): 1. Polyethylene Terephthalate (PET) for Food Packaging Applications: *International Life Science Institute (ILSI)*: Europe Packaging Material Task Force: Brussels, Belgium.

Panyakapo P. & Panyakapo M. (2007). Reuse of Thermosetting Plastic Waste for Lightweight Concrete. *Waste management*, 28, pp. 1581-1588.

Park, R., & Paulay, T. (1975). “Reinforced concrete structures”. John Wiley and Sons. New York, United State of America (USA).1975. pp. 769.

Pelisser F., Oscar Ruben Klagues Montedo (2012). Mechanical properties of recycled PET fibre in concrete. *Materials Research*, 15 (4); pp. 679-685.

Pezzi L., P. De Luca, D. Vuono, F. Chiappetta, & A. Nastro. (2006). Concrete Products with Waste’s Plastic Material (Bottle, Glass, Plate). *Materials Science Forum*, 514-516(2), pp. 1753– 1757.

Popovics. S. & J. Ujhelyi (2008). Contribution to the concrete strength versus water cement ratio relationship. *Material Civil Engineering*, 20, pp. 459-463.

Rahmani E., Dehestani M., Beygi M.H.A., Allahyarhi H., & Nikbin I.M. (2013). On the mechanical properties of concrete containing waste PET particles. *Construction and Building Materials*, 47, pp. 1302-1308.

Ramachandran, V. S. (1995). Concrete Admixtures Handbook. *Properties, Science, and Technology*, Park Ridge, New Jersey, U.S.A.: Noyes Publications.

Ramadevi K. & Manju R. (2012). Experimental investigation on the properties of concrete with plastic PET (bottle) fibre as fine aggregates. International Journal of Emerging Technology and Advanced Engineering, 2(6), pp. 42-46.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Ramezanianpur, A. A. & Malhotra, V. M. (1995). Effect of Curing on Compressive Strength, Resistance to Chloride-Ion Penetration and Porosity of Concretes Incorporating Slag, Fly Ash or Silica Fume. *Cement and Concrete Composites*, 17, pp. 125-133.

Raphael, J. M. (1984). Tensile strength of concrete. ACI J Proc, 81 (1984). pp. 158-65.
Rashid, M. A., Mansur, M. A., & Paramasivam, P. (2002). Correlations between mechanical properties of high-strength concrete. *Journal of Materials Civil Engineering*, 14 (2002), pp. 203-38.

Rebeiz K, Serhal S, & Fowler D. (1994). Structural Behaviour of Polymer Concrete Beams Using Recycled Plastics. *ASCE Journal Material Civil Engineering*, 6(1994), pp. 150–65

Redon C. & Chermant J. (1999). Damage mechanics applied to concrete reinforced with amorphous cast iron fibers, concrete subjected to compression, *Cement and Concrete Composites*, 21 (3), pp. 197-204.

Richardson A.E. & Sean Landless (2009). Synthetic fibres and steel fibres in concrete with regard to bond strength and toughness, *Built Environment Research*, 2 (2) (2009). pp. 128-140.

RILEM TC-50 FMC (1985). Determination of fracture energy of mortar and concrete by means of three point bends test on notched beams. *Materials and Structure*, 18(106), pp 285-290.

Saeed, M. O., Hassan, M. N. & Mujeebu, M. A. (2009). Development of Municipal Solid Waste Generation and Recyclable Components Rate of Kuala Lumpur: Perspective Study. Conference Paper. University Science of Malaysia; 1969.

Sahmaran M. & Ozgur Yaman (2007). Hybrid fiber reinforced self-compacting concrete with a high-volume coarse fly ash.). *Construction and Building Materials*, 21, pp. 150-156.

Sammer Hamoush, William Heard, & Brian Zornig (2010). Effect of matrix strength on pullout behavior of steel fiber reinforced very-high strength concrete composites. *Construction and Building Materials*, 25(1), pp. 39-46.

Sata,V., Jaturapitakkul, C. & Kiattikomol, K. (2007). Influence of Pozzolan from Various By-Product Materials on Mechanical Properties of High-Strength Concrete. *Construction and Building Materials*, 21**,** pp. 1589-1598.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Sedran, T., De Larrard, F., Hourst, F. y Contamines, C. (1996). Mix design of self-compacting concrete. *International RILEM Production Methods and Workability of Concrete*, Edited Bartos, D.L. & Marrs D.J. Editorial: E & FN Spon, Londres, (1996), pp. 439-450.

Sehaj Singh, Arun Shukla, & Richard Brown (2004). Pullout behaviour of polypropylene fibers from cementitious matrix, *Cement and Concrete Research,* 34 (2004), pp. 1919-1925.

Semiha Akçaözog˘lu & Cengiz Duran Atis (2011). Effect of Granulated Blast Furnace Slag and fly ash addition on the strength properties of lightweight mortars containing waste PET aggregates. *Construction and Building Materials*, 25 (2011). pp. 4052-4058.

Sengul, O. & Tasdemir, M. A. (2009). Compressive Strength and Rapid Chloride Permeability of Concretes with Ground Fly Ash and Slag. *Journal of Materials in Civil Engineering ASCE,* 21(2009), pp. 494 – 501.

Shannon O'Connell (2011). Development of a new high performance synthetic fiber for concrete reinforcement, July 2011, Dalhousie University Hailfax, Nova Scotia.

Siddique R., Khatib J. & Kaur I. (2007). Use of Recycled Plastic in Concrete: A Review. *Waste management*, 28 (2007), pp. 1835-1852.

Sikalidis C.A., A. A. Zabaniotou, & S. P. Famellos. (2002). Utilisation of Municipal Solid Wastes for Mortar Production. *Resources, Conservation, and Recycling*, 36(2), pp. 155–167.

Silva D, Betioli A, Gleize P, Roman H, Gomez L, Ribeiro J. Degradation of recycled PET fibres in Portland cement-based materials. *Cement Concrete Resources*. 2005, 35. pp. 1741-6.

Singh S.K., Jan. (2010). Polypropylene Fiber Reinforced Concrete, an overview. Central Building Research Institute, Roorkee & Honorary Secretary Institute of Engineers. CE&CR, Vol.24, No. 1.

Soroushian, P., Mirza, F. Alhozaimy A. (1995). Permeability characteristic of polypropylene fibre reinforced concrete. *American Concrete Institution Material Journal*, 92(3). pp. 291-295.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Som Md., H. (2005). Panduan mudah analisa data mengunakan SPSS Windows. Penerbit University Teknologi Malaysia Skudai Johor.

Stahli (2008). On flow properties, fibre distribution, fibre orientation and flexural behaviour of FRC. *Materials and Structures,* 41 (1). pp. 189-196.

Steven C. Chapra , Raymond P. Canale, Numerical Methods for Engineering with Personal Computer Applications, McGraw-Hill, Inc., New York, NY, 1985.

Suhad M.A. (2001). Mathematical model for the prediction of cement compressive strength at the ages of 7& 28 days within 24 hours, Master Thesis, Al-Mustansiriya University, college of engineering, Civil engineering department.

Sulapha, P., Wong, S.F., Wee, T.H. & Swaddiwudhipong, S. (2003). Carbonation of Concrete Containing Mineral Admixtures. *Journal of Materials in Civil Engineering*, pp. 134-143.

Taher Abu Lebdeh, Sameer Hamoush, William Heard, & Brian Zornig (2011). Effect of matrix strength on pullout behavior of steel fibre reinforced very high strength concrete composites. *Construction and Building Materials*, 25, pp. 39-46.

Torrijos, M. C., Barragan, B. E., & Zerbino, R. L. (2008). Physical-mechanical properties, and mesostructure of plain and fibre reinforced self-compacting concrete. *Construction and Building Materials*. 22 (2008). pp. 1780-1788.

Toutanji, H. A., and Saafi, M. (2000). "Flexural behavior of concrete beams reinforced with glass fiber-reinforced polymer (GFRP) bars." *American Concrete Institution Structural Journal*, 97(5). pp. 712-719.

Vikrant S. Vairagade, Kavita S. Kene, Dr. N. V. (2013). Investigation on Compressive and Tensile Behavior of Fibrillated. *Engineering Research and Applications*. 2 (3); pp. 1111-1115.

Wee, T.H., Lu H. R. & Swaddiwudhipong, S. (2000). Tensile Strain Capacity of Concrete under Various States of Stress. *Magazine of Concrete Research*, 52(3), pp. 185-193.

Welle, F. (2011). Twenty years of PET bottle to bottle recycling: An overview. *Resources, Conservation and Recycling*, 55 (2011). pp. 865-875.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Xu, B. W., & Shi, H. S. (2009). Correlations among mechanical properties of steel fiber reinforced concrete. *Construction and Building Materials*. 23 (2009). pp. 3468–3474.

Yan, L. & Chouw, N. (2013). Compressive and flexural behaviour and theoretical analysis of flax fibre reinforced polymer tube encased coir fibre reinforced concrete composite. *Materials and Design*. 52 (2013). pp. 801-811.

Yang, K. H., Oh, M. H., Kim, M. H. & Lee, H. C. (2010). Flexural behaviour of hybrid precast concrete beams with H-steel beams at both ends. *Engineering Structures*, 32 (2010). pp. 2940-2949.

Yang, I. H., Joh, C. & Kim, S. B. (2011). Flexural strength of ultra-high strength concrete beams reinforced with steel fibers. *Procedia Eengineering*, 14 (2011). pp. 793-796.

Zain M.F.M. & S.M. Abd, Sopian, M. Jamil (2008). Mathematical regression model for the prediction of concrete strength. MAMECTIS'08 Proceedings of the 10th WSEAS international conference on Mathematical methods, computational techniques and intelligent systems, pp. 392-396.

Zain M.F.M. & S.M. Abd. (2009). Multiple regression model for compressive strength prediction of high performance concrete. *Applied Sciences*, 9(1), pp. 155-160.

Zhang, H., & Wen, Z. (2013). The consumption and recycling collection system of PET bottles: A case study of Beijing, China. *Waste Management*, 34 (2014). pp. 987-998.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH