THE EFFECT OF HIGH TEMPERATURE ON CONCRETE CONTAINING FIBERS FROM RECYCLED PLASTIC BOTTLES

BILAL ZEB

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2017

This project report is dedicated to my Parents and my Wife

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to all those who gave me a helping hand to complete this thesis. I am particularly grateful to my supervisors **Dr. Mohd Yunus Ishak** and also **Dr. A.S.M Abdul Awal** for their valuable and constructive suggestions that helped me in completing this project. Thank you for your efforts in improving this study.

Thanks to all **technicians and individuals** who offered their help directly or indirectly in Structure laboratory. Gratitude also dedicated to all my friends who helped and supported me during the entire course of completing this thesis.

Furthermore, I wish to thank my **Parents and my Wife** who have constantly supported me throughout this entire process. Without their prayers and support I would have never completed this project.

Lastly, I am very thankful to my friend **Lemar Abdul Ghani** for helping me throughout my master project. Your cooperation and help throughout the whole laboratory work is very much appreciated.

ABSTRACT

High consumption of plastic based products has increased the volume of polymeric waste leading to several environmental problems. Utilizing plastic waste fiber is believed to offer benefits such as waste reduction and resource conservation. The properties of concrete exposed to elevated temperature are of importance in terms of structural stability and assessment of serviceability state of the structure. This study shows the behavior of concrete incorporating Polyethylene Terephthalate (PET) fibers at elevated temperature. Concrete samples with PET fibers at 0%, 0.5% and 1% are thermally treated in an electric furnace for a period of 1 hour at elevated temperatures of 200, 400, 600 and 800˚ C. Specimen are water cured for 28 days and tested for visual inspection, ultrasonic pulse velocity (UPV) and residual compressive strength. It is found out that the workability decreases with the increment of PET fibers. Furthermore, an increment in compressive strength is witnessed for concrete incorporating PET fibers with PET-FRC (0.5% fibers) showing maximum strength gain up to temperature of 400˚C. A drastic drop in residual compressive strength and UPV for all specimen is witnessed at temperatures of 600˚C and 800˚C. Vaporizing of PET fibers at elevated temperatures led to the formation of channels and air voids which reduced the strength of FRC more than PC. It is concluded that PET-FRC with 0.5% fiber volume increases the strength of concrete at lower temperatures however, at elevated temperatures the strength is significantly reduced.

ABSTRAK

Permintaan produk berasaskan plastik yang tinggi meningkat isipadu bahan buang polimerik yang membawa beberapa kesan buruk pada alam sekitar. Penggunaan serat dari bahan buangan berasaskan plastik dipercayai boleh menawarkan kebaikan seperti mengurangkan kadar bahan buangan dan memulihara sumber. Sifat konkrit yang terdedah pada suhu yang tinggi adalah istilah yang penting dalam ke kestabilan stuktur dan penilaian keadaan servisabiliti struktur. Kajian ini menunjukkan sifat konkrit yang mengandungi serat polyethylene terephthalate (PET) pada suhu yang tinggi. Sampel konkrit yang mengandungi serat PET sebanyak at 0%, 0.5% dan 1% telah melalui rawatan haba di dalam perapian untuk melebur elektrik selama satu jam pada ketinggian suhu 200, 400 dan 800 ˚ C. Spesimen dirawat dengan air selama 28 hari dan diuji secara visual, ultrasonik halaju nadi dan kekuatan mampatan. Kajian menemui bahawa kebolehkerjaan berkurangan dengan kenaikan jumlah serat PET. Tambahan pula, kenaikan kekuatan mampatan disaksikan untuk konkrit dengan serat PET 0.5% menunjukkan kekuatan maksimum yang diperolehi sehingga haba mencecah 400˚C. Penurunan secara drastik dalam kekuatan mampatan konkrit dan ultrasonik halaju nadi untuk semua spesimen pada suhu 600˚C dan 800˚C. Pengewapan serat PET pada suhu yang tinggi menyebabkan pembentukan saluran dan kekosongan udara dimana mengurangkan kekuatan konkrit bertetulang lebih dari konkrit kosong. Dapat disimpulkan bahawa kekuatan mampatan konkrit bertetulang dengan isipadu serat PET sebanyak 0.5% meningkat pada suhu yang lebih rendah, berkurang secara ketara dengan suhu yang tinggi.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Standard Testing Materials
BS	-	British Standard
FRC	-	Fiber reinforced concrete
PET	-	Polyethylene Terephthalate
M30	-	Concrete grade of 30N/mm^2
PC	-	Plain concrete
PET-FRC	-	Fiber reinforced concrete with Polyethylene Terephthalate fiber
OPC	-	Ordinary Portland Cement
W/C	-	Water Cement
PET-FRC0.5	-	Fiber reinforced concrete with 0.5% Polyethylene Terephthalate fibers
PET-FRC1.0	-	Fiber reinforced concrete with 1.0% Polyethylene Terephthalate fibers

CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete is a composite material, primarily consisting of three basic elements which are cement, aggregate and water. Concrete is relatively good in compression but weak in tension. Concrete tends to fail in a brittle manner due to its low tension resistance. To overcome some of the bitter properties of the concrete, reinforced concrete was introduced. Steel reinforcement bars are added into the concrete as an improvement to the tensile strength and to make it more ductile. However, steel reinforcement are prone to corrosion which greatly reduces the strength and durability of concrete. Thus, the attempts to improve the properties of concrete have never stopped. Besides steel reinforced concrete, a new invention of construction material called fiber reinforced concrete (FRC) has been introduced. In FRC, discrete fibers are added into a cement base matrix with an ordered or random distribution manner. In construction technology, there are many types of fibers like steel, carbon, aluminum, wood, plastic, glass, and others that can be introduced into concrete mix. Such type of concrete has wide varieties of applications in civil engineering field.

1.2 Background of Study

The development in the construction industry all over the world has increased (Ganiron, 2012). Attempts have also been made by various researchers to reduce the cost of its constituents and hence total construction cost by investigating and ascertaining the usefulness of recycled material like plastic bottles which are usually discarded. As a result of the increase in the cost of construction materials, especially cement, crushed stone (coarse aggregate), fine sand (fine aggregate), there is the need to investigate the use of alternate building materials which are locally available (Ganiron, 2013).

Polyethylene terephthalate (PET) is a member of the polyester family of polymers and it plays an important role as synthetic fiber in industrial production. PET gains its popularity due to its physical characteristics which are lightweight, colourless in natural state, semi-crystalline resin, excellent water and moisture barrier and impact-resistant where it is less breakable than other materials. Due to these characteristics, PET has become increasingly paramount among the manufacturers and consumers. The world's PET production rate is relatively high, resulting in high volume of waste production in which its annual consumption rate represents more than 300,000 million units and most of the waste is discarded to landfill. PET waste is a non-biodegradable material which does not undergo decay process and thus remains in nature for hundreds of years (Irwan *et al*., 2013).

1.3 Problem Statement

Environmental pollution has become the main concern of the society. This is because the problem of environmental pollution has become worse. Among all the types of wastes generated, plastic wastes need to be given more attention as it cannot biodegrade.

In 2008, global plastic consumption worldwide has been estimated at 260 million tons and, according to a 2012 report by Global Industry Analysts, plastic consumption is to reach 297.5 million tons by 2015 (Claire, 2009).

From the statement above, it is empirical that the quantity of plastic waste is increasing substantially. This is due to its characteristic of being lightweight, functional, durable, and inexpensive (Putatunda, 2011). Thus, people like to use it and just simply throw it away as it is cheap.

Plastic pollution involves the accumulation of plastic products on the environment which leads to affecting the wildlife, the wildlife habitat and human beings (Reddy *et al.,* 2014). Plastic products if incinerated release harmful chemicals into the soil which slowly sips into ground. The chemical will mix in the ground water and affect the quality of ground water. Ground water is one of the sources of human drinking water. This can affect the human health if the polluted water is consumed.

Waste plastic is among the most abundant non-biodegradable solid waste present in our environment. Among all different form of plastics, PET is a well-known material used in food and beverage packing products and majority of these products end up being discarded to at a landfill. These PET products such as PET bottles will not decay and remain in the environment for a very long duration of time which may trigger air watered ground pollution.

In the field of civil engineering, concrete is considered as a miraculous man made material which is widely used in developed and developing country. Concrete is the backbone of the whole world's infrastructural development (Nibudey *et al.,* 2014). Concrete possesses a lot of good properties such as relatively high compressive strength, durability, low coefficient of thermal expansion and versatility. However, there is an inherent weakness found in the concrete that is low tensile strength. Concrete tends to experience a sudden failure in brittle manner due to its inherent low tension resistance. Such kind of failure is extremely unfavorable in structural design as it does not indicate any prior sign of failure.

The increasing trend in plastic waste generation, the search for a cost-effective construction material and the problem of corrosion in reinforcement bar has made PET reinforced concrete a favourable material. The above-mentioned problems can be minimized by using concrete incorporating PET fibers.

The major problem nowadays in this world is global warming and green materials are in priority aspects for material use consideration. As a result of environmental impact associated with the increase in the general awareness of waste management, the construction industry is encouraging the use of recycled waste materials to be added as a supplement to increase the desire properties of concrete. Researchers are putting much efforts and attempts to investigate the utilization of waste fibers into the concrete mass to sustain and protect the ecosystem. The addition of recycled PET fiber reinforced concrete has attracted widespread attention. The development of new PET fiber construction materials in concrete is still considerably new and is in doubt as the physical and mechanical properties are still under preliminary study. It is still a major challenge to produce recycled plastic reinforced concrete with sufficient mechanical properties. As such, the use of recycled PET as short fibers reinforcement in structural concrete is ought to be further investigated.

1.4 Objectives

The following are the main objectives of the research:

- To investigate the fresh properties of PET fiber reinforced concrete (FRC).
- To investigate the fire endurance of PET fiber reinforced concrete exposed to high temperature in terms of visual inspection, residual weight, ultrasonic pulse velocity and residual compressive strength.
- To compare the properties of PET fiber reinforced concrete with ordinary Portland cement for the same exposure condition.

1.5 Scope of work

This study is focused on the use of PET fibers in normal Portland cement concrete, to determine its workability, density, compressive strength and fire resistance of PET- FRC at different temperatures.

The research scope will focus on:

- The percentage of PET fibers studied in this research are limited to 0%, 0.5% and 1%.
- The length of fiber is 20mm.
- The temperature in which the concrete will be tested are (27, 200, 400, 600 and 800) °C.
- The tests are conducted after 28 days of water curing.

1.6 Research Significance

Corrosion of steel reinforcement in concrete is an issue that is faced commonly in the construction industry. Corrosion reduces the strength and durability of concrete making the structure susceptible to failure. However, PET fiber reinforced concrete can be the solution to the problem of steel bar reinforcement in concrete. In this study, PET fiber as the mixture material are added to the cementitious material. This is to make sure the corrosion of steel reinforcement would not be the main reason in the deterioration of concrete strength.

Secondly, the usage of PET plastic is increasing rapidly. The plastic cannot biodegrade, thus becoming a source of environmental pollution. By adding PET plastic fiber into concrete, we can reduce the number of plastic bottles being thrown at landfill. At the same time, we can also address the corrosion problem of steel reinforcement.

Lastly with the increase in building activities, more and more structures are prone to damage from fire. Fire in a building may reach above 1000˚ C inflicting serious damage to the structure and questioning its structural integrity. There are many occasions where concrete is exposed to elevated temperatures like fire exposure from thermal processor, exposure from furnaces, nuclear exposure, etc. In such cases, understanding of the behaviour of concrete and structural members exposed to elevated temperatures is vital.

This study is thus useful as it addresses the above-mentioned problems of corrosion of steel bars in concrete, environmental pollution and damage incurring to structures at elevated temperatures.

REFERENCES

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

Akcaozoglu, S., Atis, D.C., (20 11). 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. Vol. 25, pp 4052-4058.

Batayneh, M., Marie, I., & Asi, I. (2007). Use of selected waste materials in concrete mixes. *Waste management*, *27*(12), 1870-1876.

Banthia and Mindess, (2004) Toughness Characterization of Fiber ReinforcedConcrete: Which Standard to Use ASTM, J. of Testing and Evaluation, 32(2), pp. 138-139

Banthia, N., Gupta, R., & Mindess, S. (2004). Developing crack resistant FRC overlay materials for repair applications. In *NSF Conference, Bergamo, Italy*.

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

Chen, B., & Liu, J. (2004). Residual strength of hybrid-fiber-reinforced high-strength concrete after exposure to high temperatures. *Cement and Concrete Research*, *34*(6), 1065-1069.

Chen, B., Liu, J. "Residual Strength of Hybrid-Fiber-Reinforced High-Strength Concrete after Exposure to High Temperatures", Cement and Concrete Research, Vol. 34, No. 6, pp. 1065-1069. 2003.

Choi, Y.W., Moon, D.J., Kim, Y.J., Lachemi, M., (2009). Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles. Construction and Building Materials.
Vol. 23, pp 2829-2835.

Dehn, F. "Temperature Behaviour of Ultra High-Performance Concrete (UHPC) - A Micro Analytical Reflect" International Symposium on Ultra High Performance Concrete. Kassel, Germany, pp. 731-742. 2004.

Dougill, J.W. (1983), "Materials dominated aspects of design for structural fire endurance of concrete structures," Fire Safety of Concrete Structures, SP 80-4, pp. 151- 175.

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

Fernando Pelisser, Oscar Rubem Klegues Montedo, Philippe Jean Paul Gleize and Humberto Ramos Roman. (2012). *Mechanical Properties of Recycled PET Fibers in Concrete*. Materials Research, 15(4), pp 679-686.

Frigione, M., (2010). Recycling of PET bottles as fine aggregate in concrete. Waste management. Vol. 20, pp 1101-1 106.

Fletcher, I., Borg, A., Hitchen, N., and Welch, S. (2006), "Performance of concrete in fire: a review of the state of the art, with a case study of the Windsor tower fire," in Proceedings of the fourth international workshop Structures in Fire, Aveiro, Portugal, May, 2006, pp. 779-790.

Hertz, K. (1992), "Analyses of concrete structures exposed to fire," PhD Thesis, Technical University of Denmark, DK-2800, Lyngby, Denmark

International Life Sciences Institute (ILSI) Europe Report Series. (2000). *Packing Materials : Polyethene terephthalate (PET) for Food Packaging Applications*. pp 1-16.

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

Kalifa, P., Chéné, G., Gallé, C. "High-Temperature Behaviour of HPC with Polypropylene Fibers From Spalling to Microstructure", Cement and Concrete Research, Vol. 31, No. 10, pp. 1487-1499. 2001.

Khoury, G.A. 1992. Compressive strength of concrete at high temperatures: *a reassessment. Magazine of concrete Research*, 161, 291-309.

Khoury, G.A. "Effect of Fire on Concrete and Concrete Structures", Progress in Structural Engineering and Materials, Vol. 2, No. 4, pp. 429-447. 2001.

Komonen, J., Penttala, V. "Effects of High Temperature on the Pore Structure and Strength of Plain and Polypropylene Fiber Reinforced Cement Pastes", Fire Technology, Vol. 39, No. 1, pp. 23-24. 2003.

Lakshmia and Naganb, (2011), "*Investigation on Durability Characterictics of E-plastic Waste Incorporated Concrete*." Asian Journal of Civil Engineering (Building and Housing) Vol. 12, No. 6, 773-787

Le Guern Lytle, C. (2009). When The Mermaids Cry: The Great Plastic Tide. *Retrieved*, *3*(02), 2014.

Li, Z., X. Wei, W. Li (2003). Preliminary interpretation of Portland cement hydration process using resistivity measurements. *ACI Materials Journal*, vol. 100, no. 3, pp. 253–257.

Marzouk O, Dheilly R, & Queneudec M. (2007). Valorization of Post-Consumer Waste Plastic in Cementitious Concrete Composites. *Waste Management*, 27. pp. 310– 31

Malvar, (1996). *Literature Review of Durability of Composites in Reinforced Concrete.* Naval Facilities Engineering Service Center.

Manaf, L. A., Samah, M. A. A., & Zukki, N. I. M. (2009). Municipal solid waste management in Malaysia: Practices and challenges. *Waste management*, *29*(11), 2902-2906.

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

Malaysian Plastic Industry (2012). *Market Watch 2012*. Trade Fairs in Malaysia 2012. 19-22 July. Putra World trade Center (PWTC), Kuala Lumpur, pp1 -14.

Mehta PK, Monteiro PJM. (2006). "Concrete: microstructure, properties and materials". 3th ed. New York: McGraw-Hill.

Mindess S, Young J F, and Darwin D (2003); Concrete, 2nd Ed. Pearson Education Inc. Upper Saddle River, NJ 07458

Miyazaki Kuniyuki, Okubo Seisuke Fukui Katsunori Ishikawa Tsuneo Ochi Tsuneo (2004). "*Recycling of Polyethelene Terephthalate (PET) for Short Fibers to Reinforce Concrete*", Proceedings of the Symposium on rock mechanics, pp 373-378.

Morsy, Rashad, & El-Nouhy. (2009). Effect of elevated temperature on physico-mechanical properties of metakaolin blended cement mortar. *Structural Engineering and Mechanics, 31*(1), 1-10.

Morsy, M. S., Alsayed, S. H., & Aqel, M. (2010). Effect of elevated temperature on mechanical properties and microstructure of silica flour concrete. *International journal of civil & environmental engineering, 10*(1), 1-6.

National Solid Waste Management Department, (2011). A Study on Plastic Management in Peninsular Malaysia.

Neville, A. M., "Properties of Concrete", *Pitman Books Limited*, London, England, 1983

Nibudey R. N., Nagarnaik P. B., Parbat D. K. and. Pande A. M (2014), *Compressive Strength and Sorptivity Properties of PET Fiber Reinforced Concrete*, International Journal of Advances in Engineering & Technology, 7(4), pp1206-1216.

Nicholson, P.T., Shaw, I. "Ancient Egyptian Materials and Technology" Cambridge University Press. Cambridge, MA. 2000. pp. 82

Nibudey R. N., Nagarnaik P. B., Parbat D. K. and. Pande A. M (2013), *Strength and Fracture Properties of Post Consumed Waste Plastic Fiber Reinforced Concrete*, International Journal of Civil, Structure, Environment and Infrastructure Engineering Research and Development, 3(2), pp 9-16.

Noumowé, A.N., Siddique, R., Debicki, G. "Permeability of high-performance concrete subjected to elevated temperature (600 °C)", Construction and Building Materials, Vol. 23, No. 5, pp. 1855-1861. 2009.

Ochi T., Okubo S., Fukui K. (2007), *Development of recycled PET fiber and its application as concrete-reinforcing fiber*, Cement and Concrete Composites, 29, pp 448-455.

Peng, G-F., Yang, W-W., Zhao, J., Liu, Y-F., Bian, S-H., Zhao, L-H. "Explosive Spalling and Residual Mechanical Properties of Fiber-toughened High-

Performance Concrete Subjected to High Temperatures", Cement and Concrete Research, Vol. 36, No.4, pp. 723-727. 2006.

Peng, G-F., Bian, S-H., Guo, Z-Q., Zhao, J., Peng, X-L., Jiang, Y-C. "Effect of Thermal Shock Due To Rapid Cooling on Residual Mechanical Properties of Fiber Concrete Exposed to High Temperatures", Construction and Building Materials, Vol. 22, No. 5, pp. 948-955. 2008.

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

PlasticsEurope (2013). *Plastic- the Facts 2013: An Analysis of European Lastest Plastics Production, Demand and Waste Data* [Brochure]. Europe, Association of Plastics Manufacturers.

Poon, C.S., Shui, Z.H., Lam, L. "Compressive Behavior of Fiber Reinforced High Performance Concrete Subjected to Elevated Temperatures", Cement and Concrete Research, Vol. 34, No. 12, pp. 2215-2222. 2004.

Putatunda, R. (2011). Land Pollution. *Buzzle. com*, *7*.

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.

Reddy, M. S., Reddy, P. S., Subbaiah, G. V., & Subbaiah, H. V. (2014). Effect of plastic pollution on environment.

Savva, A., Manita, P., Sideris, K.K., (2005), "Influence of elevated temperatures on the mechanical properties of blended cement concretes prepared with limestone and siliceous aggregates." *Cement and Concrete Composites*, 27, p: 239-248.

Sandaruwini A.H.W.E, Bandara K.A.J.M and Sudhira De Silva (2012). *Investigation on Mechanical Behavior Concrete with Fibers made of Recycled Materials*. Thesis, University of Ruhuna,Hapugala, Wackwella, Galle.

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.

Sinha V., Patel M. R. and Patel J. V. (2008): Pet Waste Management by Chemical Recycling: A Review. Journal of Polymers and the Environment 18(1), 8–25.

Shamskia N. (2012). The Influence of Pet Fibers on the Properties of Fresh and Hardened Concrete. Journal of Structural Engineering and Geotechnics, 2(1), pp 13-17.

Shao, Y., and Shah, S. P. (1997). "Mechanical properties of PVA fiber reinforced cement composites fabricated by extrusion processing." *ACI Materials Journal*, 94(6), 555- 564

Siddique R., Khatib J. & Kaur L (2007). Use of Recycled Plastic in Concrete : A review. Waste Management, 28, pp 1835-1852.

Sukontasukkul, P., Pomchiengpin, W., & Songpiriyakij, S. (2010). Post-crack (or post-peak) flexural response and toughness of fiber reinforced concrete after exposure to high temperature. *Construction and Building Materials*, *24*(10), 1967-1974.

Sung Bae Kim, Na Hyun Yi, Hyun Young Kim, Jang-Ho Jay Kim and Young-Chul Song (2010). Material and Structural Performance Evaluation of Recycled PET Fiber Reinforced Concrete.Cement and Concrete Composites, 32, pp232-240

Swamy, R.N., "Fibre Reinforcement of Cement and Concrete" RILEM Committee 19- FRC. Vol. 8 No. 45. 1977.

Tanyildizi, & Çevik. (2010). Modeling mechanical performance of lightweight concrete containing silica fume exposed to high temperature using genetic programming. *Construction and Building Materials*, *24*(12), 2612-2618.

Topcu IB, Demir A. Effect of fire and elevated temperature on reinforced concrete structures. Bulletin of Chamber of Civil Engineering, Eskisehir Branch,
2002; 16: 34‑6.

Travis, Q.B., Mobasher, B. "Correlation of Elastic Modulus and Permeability in Concrete Subjected to Elevated Temperatures", Journal of Materials in Civil Engineering, Vol. 22, No. 7, pp. 735-740. 2010.

T. U. Ganiron Jr, "Concrete Debris a Fine Aggregate for Architectural Finishing Mortar", *Architectural Journal*, vol. 2, no. 5, (2012).

T. U. Ganiron Jr, "Influence of Polymer Fiber on Strength of Concrete", *International Journal of Advanced Science and Technology*, vol. 55, (2013).

United Nations Environmental Programme (UNEP) Division of Technology, Industry and Economics, International Environmental technology Centre Osaka/Shiga, Japan (2009). Converting Waste Plastics into a Resource: Assessment Guidelines (revised version), pp 1 -63.

Urase, T.; Okumura, H.; Panyosaranya, s.; Inamura, A. (2008). Emission of volatile organic compunds from solid waste disposal sites and importance of heat management. Waste Manag. Res. 26, pp 534-538.

Vest H. (2003): Production and Recycling of PET-Bottles, Eschborn.

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