IJNRD.ORG ISSN : 2456-4184

INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG

An International Open Access, Peer-reviewed, Refereed Journal

Study of PET Fiber-Reinforced Green Ultra-High Performance Material

*Sanjay Kumar Bhagat

Research Scholar, Department of Civil Engineering, Ramchandra Chandravanshi University, Palamu.

** Dr. Anita Sinha

Principal RCIT, RCU, Palamu.

***Prof (Dr.) Ranjeet Kumar Singh, Professor Department of Chemistry, BIT Sindri

ABSTRACT:

This paper presents an ideal experimental design based on the response surface method (RSM) to develop a new class of Green Ultra-High Performance Fiber Reinforced Cementitious Composites (GUHPFRCCs), in which 50% of the volume contains ultrafine palm oil fuel ash (UPOFA). This green concrete is currently under development at the Universiti Sains Malaysia (GUSMRC). This could lead to the greater utilization of POFA in concrete and, subsequently, could be useful in protecting the environment by minimizing volume of waste disposed on the wasteland and minimizing emission of greenhouse gases that released during cement production, besides contribute to cost saving which could somehow contribute towards the sustainability of the concrete industry. Experimental investigations were performed to evaluate the effect of waste Polyethylene Terephthalate (PET) fibres on the mechanical properties of Green Ultra-High Performance Cementitious Composites (GUHPCCs). Ultra-fine Palm Oil Fuel Ash (UPOFA) and Silica Fume (SF) were utilised to produce GUHPCCs that consist of up to 50% UPOFA and 20% SF as a partial replacement binder with cement. PET fibres were added to the GUHPCCs at a proportion of 1% of the total mixed volume, to produce Green Ultra-High Performance PET reinforced Cementitious Composites (GUHPPCCs). The mechanical properties and flexural performance of the resulting beams and slabs, including their stress–strain behaviour and ductility, were investigated. Results showed that addition of PET fibres increases the flexural strength of GUHPPCCs beams by approximately 63.24% compared with that of the ultra-high performance concrete control at the age of 90 days. Moreover, significant improvements in the flexural capacity and ductility index of the GUHPPCCs slabs were obtained. These findings may due to the bridging effects of PET fibres. Thus, the combination of UPOFA and SF with PET fibres can produce GUHPPCCs with superior mechanical properties and enhanced ductility.

Keywords: PET fibre, palm oil fuel ash, waste plastic, ultra-high strength green concrete

INDTRODUCTION:

Most PET bottles used as beverage containers become waste after their usage, causing environmental problems. To address this issue, a method to recycle wasted PET bottles is presented, in which short fibers made from recycled PET are used within structural concrete. To verify the performance capacity of recycled PET fiber reinforced concrete, it was compared with that of polypropylene (PP) fiber reinforced concrete for fiber volume fractions of 0.5%, 0.75%, and 1.0%. Appropriate tests were performed to measure material properties such as compressive strength, elastic modulus, and restrained drying shrinkage strain. Flexural tests were performed to measure the strength and ductility capacities of reinforced concrete (RC) members cast with recycled PET fiber reinforced concrete. The results show that compressive strength and elastic modulus both decreased as fiber volume fraction increased. Cracking due to drying shrinkage was delayed in the PET fiber reinforced concrete specimens, compared to such cracking in non-reinforced specimens without fiber reinforcement (NF), which indicates crack controlling and bridging characteristics of the recycled PET fibers. Regarding structural member performance, ultimate strength and relative ductility of PET fiber reinforced RC beams are significantly larger than those of companion specimens without fiber reinforcement.

Concrete is the most widely used construction material in the world due to its high compressive strength, long service life, and low cost. However, concrete has inherent disadvantages of low tensile strength and crack resistance. To improve such weaknesses of the material, numerous studies on fiber reinforced concrete have been performed. The research results show that concrete reinforced with short plastic fibers drastically improves the performance of concrete and negates its disadvantages such as low tensile strength, low ductility, and low energy absorption capacity. Polypropylene (PP), polyethylene (PE), polyvinyl alcohol (PVA), polyvinyl chloride (PVC), nylon, aramid, and polyesters are commonly used short plastic fibers in concrete members. Among these materials, PP fibers are one of the most widely used for construction applications such as in shot Crete tunnel linings, blast resistant concrete, overlays, and pavements.

Polyethylene terephthalate (PET) is one of the most important and extensively used plastics in the world, especially for manufacturing beverage containers. The current worldwide production of PET exceeds 6.7 million tons/year and shows a dramatic increase in the Asian region due to recent increasing demands in China and India. In Korea, the production of PET bottles has grown to 130 thousand tons/year. However, most PET bottles used as beverage containers are thrown away after single usage and disposed PET bottles are managed by landfill and incineration, which are causing serious environmental problems. In order to recycle PET wastes, additional expenses are required for reprocessing. Also, color change and purity degradation limit the usage of recycled PET plastics for manufacturing new products. Thus, a more effective, less costly solution is needed for PET bottle wastes.

One possible solution is using recycled PET as short fiber reinforcement in structural concrete. It can provide crack control and ductility enhancement for quasi-brittle concrete as well as mass consumption alternative, which is an important issue in the merit of recycling wasted materials. The current applications of recycled PET in the construction industry include their use as resin for polymer concrete and synthetic coarse aggregate for lightweight concrete.

In this study, the basic material properties and drying shrinkage resistance of concrete reinforced with recycled PET fibers are evaluated. These recycled PET fibers are produced from waste PET bottles, as described later in this paper. Also, experimental study of the strength, ductility and failure mode of recycled PET fiber reinforced RC beams is performed. Based on the study results, which include comparisons with specimens containing PP fiber reinforcement, the application of recycled PET fiber reinforced concrete as a structural material is evaluated.

1. **X-ray photoelectron spectroscopy (XPS) and time-of-flight secondary ion mass spectrometry (ToF SIMS):**

XPS analysis:

Polyethylene terephthalate (PET) represents an excellent option to autologous grafts due to its extended cardiovascular applications on vascular prostheses (mainly for large diameter vascular arteries), heart valves, and surgical meshes. Bakowsky et al. studied the immobilization of heparin to develop thrombus-resistant PET grafts producing surface modification by Denier reduction to produce functional carboxyl groups. The produced groups were used as anchor sites for covalent immobilization of heparin or coimmobilization of heparin/collagen on the PET surface and were characterized by XPS.

2. **PLA binary blends with petroleum-based no degradable thermoplastics:**

PLA-PET:

Polyethylene terephthalate (PET) or (PETE) is an important commercial engineering polyester thermoplastic with good thermal and mechanical properties, low permeability, and chemical resistance. It is widely used as fibers for clothing, containers for beverages and foods, and some engineering applications, the molecular structures of PET, poly (butylene terephthalate) (PBT), and poly(trimethylene terephthalate) (PTT) are very similar, although their properties such as strength, rigidity, impact resistance, and glass transition temperature are different. Thus they could be applied in various applications.

3. **Polyethylene Terephthalate:**

Polyethylene terephthalate is commonly referred to as polyester. PET is a semiaromatic polymer synthesized from ethylene glycol and terephthalic acid. PET has a glass transition temperature of 67–81°C and melting point of 260°C. It is commonly used in industrial applications due to excellent moisture and fair oxygen barrier characteristics. One of the first research papers in melt electrospinning evaluated PET and polyethylene naphthaled blends. Researchers used thermogravimetric and differential scanning techniques to analyze the change in thermal and crystalline properties of fibers before and after electrospinning. Various grades of PET have been used for investigating the effect of intrinsic viscosity on fiber diameters. PET has also been used in new laser melt electrospinning systems, recycling of used PET bottles, process modeling, and evaluating process parameters on fiber morphology for PET/SiO_2 composite micro/nanofibers.
PET polyester is the most common thermoplastic polyester and is often called just "polyester." This often causes confusion with the other polyesters in this chapter. PET exists both as an amorphous (transparent) and as a semicrystalline (opaque and white) thermoplastic material. The semicrystalline PET has good strength, ductility, stiffness, and hardness. The amorphous PET has better ductility but less stiffness and hardness. It absorbs very little water.

PET:

Plastics consumption now days have become an integral part of our lives. The amounts of plastics consumed annually have been increasing steadily. There are several factors that contribute to the rapidly growth of plastics consumption such as low density, fabrication capabilities, long life, lightweight, and low cost of production. Plastic has been used widely in packaging, automotive and industrial applications, medical delivery systems, artificial implants, other healthcare applications, land/soil conservation, water desalination, flood prevention, preservation and distribution of food, housing, communication materials, security systems, and other uses. Large applications of plastics in all part of daily activities increase the volume of plastic waste. Table 1 shows the details about the amount of plastic consumption and plastic waste data in Malaysia in 2007.

Table 1 : Consumption rate for different types of plastic resin per day of the respondent companies based on Malaysian Plastic Manufacturers Association (MPMA) [2]

Plastic resin	kg / day
Polyethylene Terephthalate (PET)	4588
Polypropylene (PP)	12827
Polystyrene (PS)	9413
Polycarbonate	1825
Acrylonitrile butadiene styrene (ABS)	13218
Others	4966

From the Table 1, it is reported that the total amount of solid resin consume per day is 46.8 tons. From the data, it shows that the consumption of ABS represent at 28% followed by PP 27%, PS 20%, others resin 11%, PET 10%, and PC 4%. Regarding to the consumption of materials

According to Table 2, the electrical and electronics sectors lead at 39%, followed by automotive 26%, domestic 19%, packaging 10%, building and construction and agricultural sectors, each contributing 3%. According to the report from the Malaysian Plastic Industry, the increase of plastic consumption from 2010 to 2011 is 26.1%. A study done by Agamuthu shows that the plastic component generate in Municipal Solid Waste (MSW) from Kuala Lumpur is 24% by weight whereas the national mean is about 15%. Therefore, it can be concluded that in Malaysia, the consumption of plastic is between ten to 15% in 2005. PET widely known use in food and beverage packaging product and most of them will be discarded to landfill. The problem further complicated since plastic waste is undegradable and may cause environmental disturbance. Treatment method through incineration will provide toxic gas like dioxin that could be dangerous to human health. One of the potential means to the problem is to recycle the PET in construction industry. Various studies by Kim, Fraternalli , Foti, and Ochi had studied the use of PET as fiber in concrete as stated in Table 3. Study carried out by Fraternalli showed that the additional of PET fiber decrease the thermal conductivity, while increases the compressive and first crack strength, and also ultimate ductility. Ochi also proved that additional of PET fiber results of increase compressive strength. Meanwhile, in the studies done by Kim and Foti, the different results on the compressive strength were shown. Both showed that the PET fiber added decrease the compressive strength by almost nine percents of its normal strength. The properties on ductility remained the same as the added PET fiber in concrete increases its strength. Based on the previous researches, it is clearly showed contradiction of result. Therefore, a study on material properties should be carried out. The shape of PET fiber in irregular shape has yet to be tested in fiber reinforced concrete. Therefore, the straight grinded recycled PET bottle wastes that were used are in irregular shape with three different volume fractions as fiber in concrete as to figure out its mechanical properties.

Table 2 : Consumption (in %) of plastics according to industrial sectors by MPMA [2]

Sectors	Plastic consumption [%]
Domestic	19
Agriculture	3
Electrical and electronics	39
Automotive	26
Packaging	10
Building and construction	3

Table 3 : Summary of previous research

Research	Volume fraction of PET fiber [%]	Shape of PET fiber	Water-cement ratio	Compressive strength
Kim [5]	0.50, 0.75, 1.00	Strip	0.41	Decrease
Fraternalli [6]	1.00		0.53	Increase
Foti [7]	0.26	Strip & circular	0.70	Decrease
Ochi [8]	0.50, 1.00, 1.50	Monofilament	0.55, 0.60, 0.65	Increase

Experimental:

The cement used in this research was ordinary Portland cement and the mix proportions are given in Table 4. Straight PET fiber were used from recycled bottle wastes. The PET fiber were grinded using granulator machine and produced fiber in irregular shape. The grinded PET fiber passed sieve 6 to 10 mm were used. In this research, four different fiber volume fraction were studied; 0%, 0.5%, 1.0%, and 1.5%. Cylinder mold 300 mm (height) and 150 mm (diameter) were used in this research followed by the BS 1881 – 110: (1983). The mechanical properties of the PET FRCstudied are compressive strength, splitting tensile strength, and MOE. All parameter test setup were followed by BS 1881 – 116, 117 & 121. Samples were prepared for three different duration; seven, 14, and 28 days.

Table 4 : Mix proportion

Specimens	W/C ratio	Unit weight [kg/m³]				Fiber volume fraction [%]	Density of PET [kg/m³]
		C*	FA*	CA*	W*		
NC*	0.65	290	900	982	185	0	0
PET FRC 0.5						0.5	0.9
PET FRC 1.0						1.0	1.8
PET FRC 1.5						1.5	2.7

**NC = Normal concrete, C = Cement, FA = Fine aggregate, CA = Coarse aggregate, W = water*

Green Ultra-High Performance:

A green type of ultra-high-performance concrete at the University of Sherbrooke using ground glass powders with different degrees of fineness (UHPGC). In UHPGC, glass is used to replace quartz sand, cement, quartz powder, and silica-fume particles. UHPGC design is based on particle packing density, mechanical properties, and specific rheology. Mixes are designed to suit the rheology and mechanical performances of different concrete applications.

A typical UHPC mix contains portland cement, silica fume (SF), quartz powder (QP), quartz sand (QS) with a maximum size of 600 μm (1/42″), and possibly steel fiber (Richard and Cheyrezy, 1994 and 1995; de Larrard and Sedran, 1994; Roux et al., 1996; Schmidt and Fehling, 2005; Lee et al., 2005). Such typical mixes have a very low water-to-binder ratio (w/b) and high superplasticizer contents. Depending on composition and curing temperature, this material can exhibit compressive strength (fc) of up to 150 MPa (21756 psi), flexural strength in excess of 15 MPa (2176 psi), and elastic modulus above 50 GPa (7252 ksi) (Matte et al., 2000; Schmidt and Fehling, 2005). It can also resist freeze–thaw and scaling cycles without any damage, and it is nearly impermeable to chloride-ion penetration (Richard and Cheyrezy, 1994). These outstanding characteristics of UHPC are achieved by enhancing homogeneity, eliminating coarse aggregate, enhancing the packing density by optimizing the granular mixture through a wide distribution of powder size classes, improving matrix properties, incorporating pozzolanic materials, reducing the w/b, improving the microstructure, applying post-set heat treatment, and enhancing ductility by including small steel fibers (Matte et al., 2000). When producing cement-based materials, consideration must be given not only to good mechanical and durability characteristics, but also to the environmentally friendly, ecological, and socioeconomic benefits (Aïtcin, 2000). A typical UHPC design has a cement content of 800 to 1000 kg/m3 (0.6 to 0.75 t/yd3) (Richard and Cheyrezy, 1994 and 1995). This high cement content not only affects production costs and consumes natural sources; it also negatively affects the environment through CO2 emissions and greenhouse effect (Aïtcin, 2000). The QP has an immediate and long-term harmful effect on the human health because it is human carcinogen. Because of the large difference in grain-size distributions between portland cement and ultrafine SF, high amount of ultrafine SF (25% to 30% by cement weight) have to be used to fill the pores between the cement particles. This significantly decreases the workability of UHPC and increases concrete cost. All these drawbacks are considered as impediments to the wide use of UHPC in the concrete market. Despite that the post-consumption glass can be recycled in many countries several times without significantly altering of its physical and chemical properties, large quantities of glass cannot be recycled because of high breaking potential, color mixing, or expensive recycling cost (Shi et al., 2005). Most waste glass is dumped into landfills, which is undesirable because it is not biodegradable and not very environmentally friendly (Roz-Ud-Din and Parviz, 2012). Attempts in recent years have been made to use waste-glass powder (GP) as an alternative supplementary cementitious material (ASCM) or ultrafine filler in concrete, depending on its chemical composition and particle-size distribution (PSD) (Shao et al., 2000; Roz-Ud-Din and Parviz, 2012). GP with a mean-particle size (d50) finer than 75 µm (0.003″) exhibits pozzolanic behavior, which contributes to concrete strength and durability (Idir et al., 2011; Cong and Feng, 2012; Vaitkeviciuset et al., 2014). GP can be used to partially replace cement in different types of concrete (Juengera and Ostertag, 2004; Andrea and Chiara, 2010; Zerbino et al., 2012; Soliman et al., 2014), which significantly decreases the adverse effects caused by alkali–silica reaction (de Larrard, 1999). Based on this research, incorporating waste GP in concrete provides high value and feasibility because of the economic and technical advantages.

UHPGC Description:

UHPGC is a new type of UHPC that is a sustainable concrete incorporating granulated postconsumer waste glass ground to a specific fineness (Tagnit-Hamou and Soliman, 2014). Glass sand (GS) can replace QS; GP can partially replace cement and completely replace QP; and fine glass powder (FGP) can partially replace SF. UHPGC mix designs were developed by optimizing (1) the packing density of the granular materials using the compressible packing model (de Larrard, 1999), (2) w/b and high-range-water reducing admixture (HRWRA) dosage using a full-factorial design approach, and (3) fiber content (Tagnit-Hamou and Soliman, 2014). Figure 1 presents the continuous particle-size distributions (PSDs) of the combination of the all ingredients to produce UHPGC. The w/b and HRWRA dosage used in UHPGC are optimized to produce concrete with certain rheological characteristics and strength requirements. The fiber content is optimized without significant alteration of the rheological properties of the fresh mixture. The fiber optimization depends mainly on the fiber type and content.

First International Interactive Symposium on UHPC – 2016
Green Ultra-High-Performance Glass Concrete

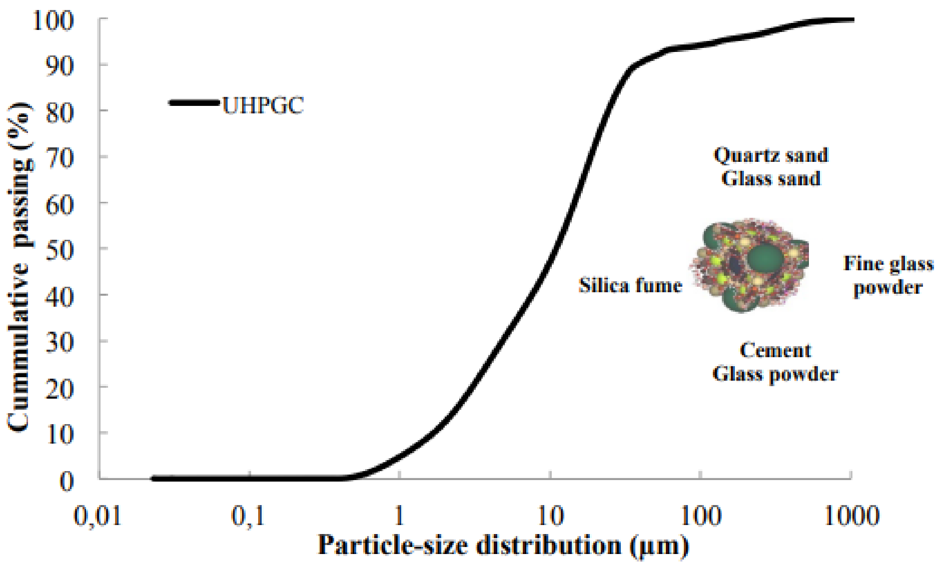

Figure 1. Particle-Size Distribution of UHPGC (1000 µm = 0.039″)

UHPGC can be produced with a lower water-to-binder ratio (w/b) due to the glass particles with zero absorption. UHPGC has enhanced rheological properties, so that it is practically self-placing without the need for internal vibration. UHPGC has enhanced rheological properties and workability due to the glass particles' zero adsorption. Depending on composition and curing temperature, UHPGC's fc can range from 130 to 260 MPa (18855 to 37710 psi), while it's flexural strength (ffl) can exceed 15 MPa (2176 psi), tensile strength (fsp) exceed 10 MPa (1450 psi), and elastic modulus (Ec) exceed 45 GPa (6527 ksi). UHPGC is characterized by excellent durability due to high packing density and lack of interconnected pores. This concrete has negligible chloride-ion penetration, low mechanical abrasion, and very high resistance to freeze - thaw cycles and deicing chemicals (Tagnit-Hamou and Soliman, 2014). UHPGC can be considered an innovative low-cost, sustainable, and green UHPC.

Conclusions:

This paper presented the results of mechanical properties of PET FRC which are compressive strength, splitting tensile strength, and modulus of elasticity. Comparison with normal concrete is also presented. The compressive strength, tensile splitting strength and modulus of elasticity value have increase with 0.5% PET fiber content in the concrete mix in compare to normal concrete. Concrete containing 1% and 1.5% PET fiber is lower than the normal concrete in compressive and splitiing tensile strength and elastic modulus. Therefore it is concluded that, the fiber content will affect the strength of the concrete. The strong fibers are desired and used to improve concrete strength and ductility, but may lead to loss in segregation, increased porosity, and overall reduction in concrete strength. In addition, high dosages of fiber will cause workability problems because of their relatively surface area. The addition of this essentially PET fiber is an option to construction industry. It is a better means of recycling waste plastic resulted to a sustainable environment.

A new type of UHPC has been developed using waste-glass materials, resulting in UHPGC. The new material exhibited excellent workability and rheological properties due to the zero absorption of the glass particles as well as the material's optimized packing density. The UHPGC evidenced an improved microstructure with higher mechanical properties and superior durability properties comparable to conventional UHPC. The UHPGC can be developed with different mix designs for various construction applications. The mechanical properties of the UHPGC made it possible to design two footbridges with reduced cross sections (about a 60% reduction in concrete volume compared to normal concrete). The UHPGC's improved durability performance can reduce maintenance costs. The construction of footbridge at the University of Sherbrooke with the UHPGC demonstrates the material's potential for large-scale production. The UHPGC can be used to build highly energy-efficient, environmentally friendly, affordable, and resilient structures. It can save the money spent for the treatment of glass cullets and their disposal in landfills.

References

1. Aïtcin, P-C. "Cements of Yesterday and Today – Concrete of Tomorrow," Journal of Cement and Concrete Research, Vol. 30, No. 9, 2000, pp. 1349–1359.
2. Cong, K.S. and Feng, X., "The Effect of Recycled Glass Powder and Reject Fly Ash on the Mechanical Properties of Fiber-Reinforced Ultra-high Performance Concrete," Advanced Material Science Engineering, Article ID 263243, 2012, pp. 8.
3. de Larrard, F., "Concrete Mixture Proportioning: A Scientific Approach," CRC Presas 1999, pp 448.
4. D.-J. Kim *et al.* Comparative flexural behavior of four fiber reinforced cementitious composites Cem Concr Compos (2008).
5. K.S. RebeizB.W. Jo *et al.* Uniaxial creep behavior and prediction of recycled PET polymer concrete Constr Build Mater (2007)
6. B.W. Jo *et al.* Mechanical properties of polymer concrete made with recycled PET and recycled concrete aggregates Constr Build Mater (2008)
7. Y.W. Choi *et al.* Effects of waste PET bottles aggregate on the properties of concrete Cem Concr Res (2005)
8. R.F. Zollo Fiber-reinforced concrete: an overview after 30 years of development Cem Concr Comp (1997)
9. O. Cengiz *et al.* Comparative evaluation of steel mesh, steel fibre and high-performance polypropylene fibre reinforced shotcrete in panel test Cem Concr Comp (2004).
10. V.C. Li *et al.* Repair and retrofit with engineered cementitious composites Eng Fract Mech (2000)
11. B. Mu *et al.* Short fiber-reinforced cementitious extruded plates with high percentage of slag and different fibers Cem Concr Res (2000)
12. N. Banthia *et al.* Fracture toughness of micro-fiber reinforced cement composites Cem Concr Com (1996)
13. M.Z. Bayasi *et al.* Composite slab construction utilizing carbon fiber reinforced mortar ACI Struct J (1997)
14. H.V. Dwarakanath *et al.* Deformational behavior of fiber-reinforced concrete beams in bending J Struct Eng ASCE (1992)
15. V.C. Li *et al.* Engineered cementitious composites for structural applications J Mater Civil Eng ASCE (1998)
16. T. Kanda *et al.* Interface property and apparent strength of a high-strength hydrophilic fiber in cement matrix J Mater Civ Eng ASCE (1998)
17. Mwangi JPM. Flexural behavior of sisal fiber reinforced concrete beams. PhD thesis. University of California Davis…
18. de Larrard, F. and Sedran T., "Optimization of Ultra-High-Performance Concrete by the Use of a Packing Model," Journal of Cement and Concrete Research, Vol. 24, No. 6, 1994, pp. 997– 1009.
19. Lee, M.-G. Chiu, C.-T. and Wang, Y.-C., "The Study of Bond Strength and Bond Durability of Reactive Powder Concrete," Journal of ASTM International, Vol. 2, No. 7, 2005, pp. 104–113.
20. Matte, V. Moranville, M. Adenot, F. Riche, C. and Torrenti, J.M., "Simulated Microstructure and Transport Properties of Ultra-High Performance Cement-Based Materials," Journal of Cement and Concrete Research, Vol. 30, No. 12, 2000, pp. 1947–1954

21. Richard, P. and Cheyrezy, M., "Reactive Powder Concretes with High Ductility and 200-800 MPa Compressive Strength," ACI SP 144, 1994, pp. 507–518.
22. Richard, P. and Cheyrezy, M., "Composition of Reactive Powder Concretes," Journal of Cement and Concrete Research. Vol. 25, No. 7, 1995, pp. 1501–1511. Roux, N. Andrade, C. and Sanjuan M., "Experimental Study of Durability of Reactive Powder Concretes," Journal of Materials in Civil Engineering, Vol. 8, Issue 1, 1996, pp. 1–6
23. Schmidt, M. and Fehling, E., "Ultra-High-Performance Concrete: Research, Development and Application in Europe," ACI SP, Vol. 225, 2005, pp. 51–77.
24. Shi, C. Wu, Y. Riefler, C. and Wang, H., "Characteristic and Pozzolanic Reactivity of Glass Powders," Journal of Cement and Concrete Research, Vol. 35, 2005, pp. 987–993.
25. Roz-Ud-Din, N. and Parviz, S., "Strength and Durability of Recycled Aggregate Concrete Containing Milled Glass as Partial Replacement for Cement," Journal of Construction and Build Materials, Vol. 29, 2012, pp. 368–77.
26. Idir, R. Cyr, M. Tagnit-Hamou A. Pozzolanic properties of fine and coarse color-mixed glass cullet [J]. Cem Concr Compos, 2011, 33(1): 19-29.
27. Vaitkevicius, V. Serelis, E. and Hilbig, H., "The Effect of Glass Powder on the Microstructure of Ultra-High Performance Concrete," Journal of Construction and Building Materials, Vol. 68, 2014, pp. 102–109.
28. Juengera, M.C.G. and Ostertag, C.P., "Alkali–Silica Reactivity of Large Silica Fume-Derived Particles," Journal of Cement and Concrete Research, Vol. 34, 2004, pp. 1389–402.
29. Soliman, N. Aïtcin, P.-C. and Tagnit-Hamou, A., "New Generation of Ultra-High Performance Glass Concrete," Advanced Concrete and Technologies. Lightweight and Foam Concretes. Education and Training, Publisher: RILEM and CEB-fib, ISBN 978-5-7264-0809-5, V. 5, Chapter 24, May 12-16, 2014, pp 218-227.
30. Zerbino, R. Giaccio, G. Batic, O.R. and Isaia, G.C., "Alkali–Silica Reaction in Mortars and Concretes Incorporating Natural Rice Husk Ash," Construction and Building Materials, Vol. 36, 2012, pp. 796–806. Siddique R., Khatib J. & Kaur I. (2007). Use of recycled plastic in concrete: A review. Waste management, 28(2008). pp. 1835-1852.
31. Wahab D.A., Abidin A. & Azhari C.H. (2007). Recycling Trends in the Plastics Manufacturing and Recycling Companies in Malaysia: Journal of Applied Sciences 7 (2007). pp. 1030-1035.
32. The Market Watch (2012). The Malaysian Plastic Industry. "Malaysia's economy attains 7th position", New Straits Times. (2012)
33. Agamuthu P. & Faizura P.N. (2005). Biodegradability of degradable plastic waste. Waste management. 23(2). pp. 95-100.
34. Kim et al. (2010). Material and structural performance evaluation of recycled PET fiber reinforced concrete. Cement & Concrete Composites. 32(2010). pp. 232-240.
35. Fraternali et al. (2011). Experimental study of thermo-mechanical properties of recycled PET fiber-reinforced concrete. Composites Structures. 93(2011). pp. 2368-2374.