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Potential use of Plastic Waste as Construction Materials: Recent Progress and Future Prospect

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Abstract. Plastic associates products based have been considered as the world most consumer packaging solution. However, substantial quantities of plastic consumption have led to exponential increase of plastic derived waste. Recycling of plastic waste as valued added product such as concrete appears as one of promising solution for alternative use of plastic waste. This paper summarized recent progress on the development of concrete mixture which incorporates plastic wastes as partial aggregate replacement during concrete manufacturing. A collection of data from previous studies that have been researched which employed plastic waste in concrete mixtures were evaluated and conclusions are drawn based on the laboratory results of all the mentioned research papers studied.

1. Introduction

According to Rochman, Browne [1], in the year 2012 alone, it was estimated that about 280 million tonnes of plastic has been produced worldwide. From that amount, about 130 million tonnes of the plastics were landfilled or recycled. Of the remaining 150 million tonnes, plastic will find their place in daily lives of human being. Meanwhile, the rest of the plastic fraction find their final way as litters in the oceans or landfilled. Consequently, the plastic waste brings serious environmental threat to modern society because it is made up from several toxic chemicals, and therefore plastic pollutes soil, air and water if not properly managed or treated [2, 3]. Accordingly, when most of the available plastic today is made up from non-biodegradable sources, land-filling by using plastic would mean burying the harmful material for over a period until it naturally degrades. In their original condition, any plastic materials would increase the waste volume during landfilling. However, their degradation rate and bulky in nature creates environmental risks tremendously. Besides, the plastic waste mass may hinder the ground water movement [4]. Plastic waste may usually in the form of film and hard plastic may contains harmful metal based elements such heavy metal, at which when mixed up with water or rain

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water can impede soil and receive water. Besides, plastic garbage can impede the rate of percolation and in turns would deteriorate the soil fertility if it is mixed with soil [4]. Moreover, plastic waste which is mostly disposed into surface water, public drain, river or sea water can create imbalance of the water and aquatic life [5].

Aquatic life such as plants and animals might have entangled with plastic waste, which can damage their health. According to The Star newspaper article [6], Malaysians, in general generate about 30,000 metric tonnes of solid waste each day. In particular, plastic waste makes up about 13% of solid waste composition, which means that about 4,000 metric tonnes of plastic waste are generated across Malaysia daily. Until now, Malaysia has yet to fully utilize on the relentless advantages of recycled plastics, which can be applied in road construction or pavement to improve strength and increase the road durability, as insulator or conduit in building construction, as raw material or fibre for textiles manufacturing, as fasteners for bulk items tying, low strength plastic furniture and other post-consumer goods. As far as the authors are concern, recycling plastics is a feasible option as an alternative way from common waste stream destination. Because plastic waste is derived from hydrocarbon-based material, its exert relatively high calorific value which can be used for incineration or boiler. However, burning of plastics at lower temperature may releases toxic and poisonous chemical gases into the air, including dioxins which is harmful to the human being. Plastic waste can also be used to produce new plastic based products after submitting to reprocessing line [7]. However, this method is seen uneconomical because the recycled plastic degrades in quality over time and thus there is growing demand for new plastic for the original product.

In terms of civil engineering application, recycling of plastic waste as cementitious based materials, such as cement mixtures or concrete mixture appear as better option for alternative plastic waste disposal. This is due to its economic and ecological advantages which can substitute or replace certain portion of aggregate in concrete mix. Besides, some alteration method of plastic waste could be ideal candidate as lightweight concrete pavement with low strength application. As such, there are already a lot of published reports that have been studied concerning the ability of plastic waste mixed together with cementitious based mixtures such as polyethylene terephthalate (PET) bottle [8, 9], polyvinyl chloride (PVC) pipe [10], high density polyethylene (HDPE) [11], spent plastic waste [12], expanded polystyrene foam (EPS) [13], glass reinforced plastic (GRP) [14], polycarbonate [15], thermoplastic recycled polystyrene [16], polypropylene fiber [17] as an aggregate, or mixture in the manufacturing of concrete.

In general, plastic is lightweight, water retainer and resistant, expandable, strong, and very cheap to produce. These are the attractive qualities that contribute to over-consumption of plastic based goods. Instead, if plastic is 100% made from hydrocarbon intermediates, it is very durable and lead to slow degradation. According to Plastic-Pollution Organization, plastic materials that are used in our daily consumption has become attractive that initiate an undeniable behavioural needs which led to over-consuming. This behaviour simultaneously pollutes the environment seriously. Previous review on application of plastic waste in concrete manufacturing has been reported previously [2, 18]. However, there is a very limited information on the post-consumer plastic utilization for their detail physical and chemical properties. This review aims to provide summary on recent progress of plastic derived waste utilization as partial aggregate replacement for concrete mixture and their future prospects for the efficient plastic waste diversion.

1.1. Current Scenario of Plastic Waste

In general, plastics are mostly used in diverse types of application daily. From industrial to family consumption, plastic is considered as universal material that can resolve wide range of problems. However, it has been found that and plastic items end up in the waste stream even after a single use only within a short period of time after purchasing especially for packaging purpose [19]. According to [18] plastic waste can be treated either by landfilled or incineration of recycled back based on municipal solid waste hierarchy. Due to technological advancement, landfilling of plastic waste is considered the least preferable method because it requires a large space, reduce the landfill lifespan and causes persistent pollution problems. Incineration process is adopted in some developed countries because of high combustible value of the plastic material and exhibit low moisture content. Thus, complete elimination of this waste and their successful rate is high as compared to Asia countries. This is because, most of the plastic especially plastic film used by most of Asia's community are rich with moisture. These properties impede the ability of incinerator to completely burn off these waste that may produce a great amount of dioxins if the temperature is lower than 800 °C. Until now, only EU has documented data on plastic production made available to the public but not for Asia countries. Figure 1 shows recent statistic on plastic production worldwide. The trend shows that the production of plastic throughout the world is increasing over times. The rest of the world has been produced more than 1,986 million tonnes of plastic since 2005. This staggering increase of plastic production worldwide shows that there is no clear indicator when the transformation from plastic based production will shift into alternative type of plastic substitute because the end destination of the plastic, if not properly managed and disposed will find their way in landfills, rivers, or sea.

1.2 Alternative Use of Plastic Waste

There are a lot of studies have been reported and published concerning the alternative use of plastic waste into different type of products [20-24]. Plastic waste formed for high grade resins have been recycled from used and spoilt plastics including: automotive parts, home appliances, cloths (textiles), mulches, and films. Accordingly, plastic waste treatment and reprocessing techniques could be divided into four major categories which are re-cycling, mechanical, chemical and energy recovery as reported by Al-Salem, Lettieri [19]. Meanwhile, Ishaiba [25] described types of plastic and their potential recycling techniques as shown in Table 1. Based on the table, common types of plastics that are mostly reprocessed including polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET), polypropylene (PP) and polyethylene (PE).

Table 1. Plastic types and their potential recycling method [25].

Plastic source	**Characteristics**	**Common use of virgin plastic**	**Common use for recycled plastic**
Polyethylene Terephthalate (PET)	Clear hard plastic, suitable for fibre	Soft drink and mineral water bottles	Clear and soft film for Packaging and wrapping, rug fibers, rain coats
Low density polyethylene (LDPE)	Soft, flexible plastic, milky white, unless a pigment is added	Lids of food containers, garbage bags, and rubbish bins	Soft film, wrapping industry, plant packaging and nurseries bags
High density Polyethylene (HDPE)	Commonly used plastic in white or coloured	Puckered shopping bags, milk storage bags (freeze)	Compost bins, detergent bottles, crates, and mobile rubbish bins
Unplasticised Polyvinyl chloride (UPVC)	Hard rigid plastic, clear type	Sanitary piping, plumbing pipes and fittings	Dishwasher bottles, toiletries detergent bottles, tiles, and plumbing pipe fittings
Plasticized Polyvinyl chloride (PPVC)	Flexible, clear, elastic Plastic	Garden hose, shoe soles, blood bags and tubing	Hose inner core, and industrial flooring
Polypropylene (PP)	Hard, but flexible plastic	Ice-cream containers, potato crisp bags,	Compost bins, kerb side recycling crates,

		stools and chairs	and worm factories
Polystyrene (PS)	Stiff but brittle plastic. Clear in nature and glossy	Cheap, transparent kitchen ware, light fittings, bottles, toys, and food containers	Laundry pegs, coat hangers, and video/CD boxes
Polyester (EPS)	Foamed, lightweight, energy absorbing, and thermal insulation	Hot drink cups, and takeaway food containers	spools, rulers, and video/CD boxes
Polyamides (PA)	Nylons	fibers, toothbrush bristles, and fishing lines	

Even though there are diverse types of recycling techniques for plastic waste as mentioned earlier, the reuse of plastic waste for construction materials can be considered as a promising method to maximize this waste. Through this method, plastic waste can be revitalized directly it disposed by substitute the plastic waste for partial aggregate replacement could enhance the environment sustainability or construction materials.

2. Plastic Aggregates and Plastic Fiber in Concrete Mix

Concrete is made up from coarse and fine aggregates, cement and water. Concrete is the most prevalent construction materials due to the fact that the raw materials are easily available and relatively low cost [26]. It also provides better fire resistance than any other building materials. Traditionally, concrete contains numerous weakness and flaws if no appropriate preconditioner is in place. For example, propagation of micro cracks of concrete under uniform concentrated applied load can be contributed to low tensile strength of concrete. Therefore, it is expected better performance of concrete structure that can withstand higher tensile strength as well as the flexural strength which could be obtained by introducing closely spaced fibres. As a matter of fact, concrete can withstand higher compression stress but low in tensile strength. In normal concrete mix, aggregate typically accounts for 65 to 85% of the mass concrete volume. In addition, aggregate plays a significant role in concrete strength development which can be characterised based on their slump value, compressive strength, dimensional stability, and durability [8]. Therefore, by replacing partial aggregate utilization in concrete mix preparation will provide alternative solution to the other potential use of plastic wastes.

Briefly, there are two forms of plastics waste which are plastic aggregate (PA) and plastic fibre (PF) commonly employed for building materials as described by Gu and Ozbakkaloglu [18]. PAs are employed to replace coarse aggregates (CA) and fine aggregates (FA). Normally, the PA possess lower bulk density than granite, limestone or basalt. Therefore, they are preferably being employed for lightweight concrete. PAs can be obtained by applying mechanical recycling method. In contrast, plastic fiber (PF) are used as reinforcement which can replace common steel fibre that can improve mechanical and strength durability [26]. The major drawbacks of common steel fibre as concrete reinforcement are their susceptible to corrosion especially on concrete surface when exposed to marine or saline water without having appropriate protection. Table simplifies the characteristics of PFs used in the concrete manufacturing. The tables also describe the source and method use to obscure PA and PF that have been reported in literature elsewhere.

2.1 Application of Plastic Waste in Concrete Mix

There are a lot of important factors need to be considered when applying plastic waste ad partial aggregate replacement. As for the present work, authors attempt to summarizes all the reported literatures mentioning concrete properties based on selective work. Physical properties of concrete, may include density, slump value, mechanical properties, covering splitting tensile strength, compressive strength, Young modulus, flexural strength, abrasion resistance, impact resistance and pulse velocity, durability properties including change in strength, chloride attacks, absorption, creep, shrinkage, carbonization, sulfide attack and several others physical and chemical properties are discussed. Table 3 simplifies some of the requirement when conducting test on the prepared concrete samples.

Table 2. Characteristics of plastic aggregate and plastic fiber and their characteristics.

Parameter	**Plastic source**	**Reference**
Plastic type	PET bottle ground into pieces and sieve according to sieve size	[2, 27-29]
	High density polyethylene (HDPE)	[30]
	Expanded polystyrene (EPS) crushing and form bead	[31]
	PVC pipe crushed to aggregate	[32]
	PET fibers from melting process	[33]
	Glassfiber reinforced plastic (GRP) fiber	[34]
	PET plastic bottle shredded into fiber	[35]
	Virgin plastic as partial fine aggregate	[36]
	Glass reinforce plastic fiber	[37]
	Polyurethane (PUR) foam waste as coarse aggregates	[38]
Size (Typical)	2-11 mm (Coarse aggregate) <2.36 mm (Fine aggregate)	[26]
	0.02 µm to 600 µm	[34]
	Microplastic - diameter ranges from 5 to 100 mm and length is 5–30 mm	[39]
	Macro plastic 30–60 mm and cross section of 0.6–1 mm^2	[40]
	Coarse aggregate (8/20 mm)	[38]
Density (kg/m^3)	Concrete aggregate (220-240) Fine aggregate (310-340)	[41]
	PET lightweight (844)	[42]
	38 113 225	[37]

	337	

Table 3. Test requirement for concrete mix preparation form plastic waste.

Test	**Factors to be considered**	**Possible contribution to strength development**
Slump	Water/cement ratio Substitution level of plastic aggregate/fiber Shape of plastic aggregate /fiber	Generally, increasing the amount of PA/PF would reduce the slump value Due to non-uniform shape of PA/PF Low fluidity Absorption capacity Aggregate with different specific gravity
Unit weight and density	Amount of PA or PF Substitution level of plastic aggregate/fiber Shape of plastic aggregate /fiber	Generally, increasing the level of substitution reduce the density for PA Similar observation, if using PF, little changes of density
Air content	Amount of air content	Incorporation of PA and PF increase the air content Due to plastic and natural aggregate could not bind together thus increase porosity
Compressive strength	Water/cement ratio Substitution level of plastic aggregate/fiber Shape of plastic aggregate /fiber Aspect ratio and geometry of fibers	Increasing the Water/cement ratio or substitution level of plastic aggregate/fiber led to reduction in compressive strength Due low elastic modulus Due to low bond strength between surface of plastic and aggregate If using high ultimate tensile strength fiber would increase compressive strength (i.e: polypropylene) than PET fiber
Splitting tensile	Substitution level of plastic	Increasing Substitution level of

strength	aggregate/fiber Shape of plastic aggregate /fiber	plastic aggregate would reduce tensile strength Due to non-uniformity shape of PA/PF Due to change in modulus elasticity However, not the case for PF Increasing amount of PF increased tensile strength (i.e PET, PP)
Elastic modulus (E_c)	Substitution level of plastic aggregate/fiber Shape of plastic aggregate /fiber Type of waste plastic Porosity of aggregates Transition zone characteristics	Ec of PA concrete much lower than conventional concrete with the same w/c Significant lower of Ec can be observed if the shape of PA become more irregular For the case of PF, not much different in Ec as in conventional concrete

3. Future prospect

This paper presents a critical review of the recent published reports on the for plastic waste based materials for aggregate replacement in concrete mix. Many studies reported in recent years on these materials indicate that the use of recycled plastic aggregates and fibers as partial aggregate replacement is gaining significant interests from many researchers. The findings of the review also show that the use of these materials can improve concrete properties under appropriate mix composition with the main motivation is to find alternative destination of the plastic wastes rather than direct disposal at the landfill. This is because, if optimum solution of plastic waste can be realized, it is estimated that about 30% of total waste disposed from solid waste could be reduced. As far as the authors are concern, most of the plastic derived based polymeric are difficult to be degraded for decades, even for centuries. By utilizing this waste as partial aggregate replacement, it could be inferred that these materials could be preserved inside concrete structures for ages. Although no studies have yet to forecast the service life of concrete structures containing plastic waste materials, the use of plastic waste in concrete can contribute meaningfully toward a more sustainable and holistic construction industry. Thus, long-term performance of plastic waste in concrete, and their environmental impact after its service life are recommended to be explored further.

4. References

[1] Rochman, C.M., et al., *Policy: Classify plastic waste as hazardous.* Nature, 2013. **494**(7436): p. 169-171.
[2] Saikia, N. and J. de Brito, *Use of plastic waste as aggregate in cement mortar and concrete preparation: A review.* Construction and Building Materials, 2012. **34**: p. 385-401.
[3] Kamaruddin, M.A., et al. *Resource recovery from municipal solid waste by mechanical heat treatment: An opportunity*. in *AIP Conference Proceedings*. 2017. AIP Publishing.

[4] Silva, R., J. De Brito, and R. Dhir, *Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production.* Construction and Building Materials, 2014. **65**: p. 201-217.
[5] Kamaruddin, M.A., M.S. Yusoff, and A.H. Ahmad. *Waste to Wealth: Recovery of Recyclable Items and Biodegradable Wastes from Night Markets at Seberang Perai Selatan, Penang*. in *Applied Mechanics and Materials*. 2015. Trans Tech Publications.
[6] Star, T., *Saturday, 21 January 2017 Solving the plastic problem.* http://www.thestar.com.my/opinion/letters/2017/01/21/solving-the-plastic-problem/, 2017.
[7] Bogas, J.A., J. de Brito, and J.M. Figueiredo, *Mechanical characterization of concrete produced with recycled lightweight expanded clay aggregate concrete.* Journal of Cleaner Production, 2015. **89**: p. 187-195.
[8] Saikia, N. and J. de Brito, *Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate.* Construction and building materials, 2014. **52**: p. 236-244.
[9] Iucolano, F., et al., *Recycled plastic aggregate in mortars composition: Effect on physical and mechanical properties.* Materials & Design, 2013. **52**: p. 916-922.
[10] Binici, H. and O. Aksogan, *Eco-friendly insulation material production with waste olive seeds, ground PVC and wood chips.* Journal of Building Engineering, 2016. **5**: p. 260-266.
[11] Shanmugapriya, M. and H. Santhi, *Strength and Chloride Permeable Properties of Concrete with High Density Polyethylene Wastes.* International Journal of Chemical Sciences, 2017. **15**(1).
[12] Jha, J., et al., *Behavior of plastic waste fiber-reinforced industrial wastes in pavement applications.* International Journal of Geotechnical Engineering, 2014. **8**(3): p. 277-286.
[13] Sayadi, A.A., et al., *Effects of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete.* Construction and Building Materials, 2016. **112**: p. 716-724.
[14] Pastor, J., et al., *Glass reinforced concrete panels containing recycled tyres: Evaluation of the acoustic properties of for their use as sound barriers.* Construction and Building Materials, 2014. **54**: p. 541-549.
[15] Wang, J., et al., *Morphologies and properties of polycarbonate/polyethylene in situ microfibrillar composites prepared through multistage stretching extrusion.* Journal of Applied Polymer Science, 2014. **131**(7).
[16] Dalhat, M. and H. Al-Abdul Wahhab, *Properties of Recycled Polystyrene and Polypropylene Bounded Concretes Compared to Conventional Concretes.* Journal of Materials in Civil Engineering, 2017. **29**(9): p. 04017120.
[17] Yang, S., et al., *Properties of self-compacting lightweight concrete containing recycled plastic particles.* Construction and Building Materials, 2015. **84**: p. 444-453.
[18] Gu, L. and T. Ozbakkaloglu, *Use of recycled plastics in concrete: A critical review.* Waste Management, 2016. **51**: p. 19-42.
[19] Al-Salem, S.M., P. Lettieri, and J. Baeyens, *Recycling and recovery routes of plastic solid waste (PSW): A review.* Waste Management, 2009. **29**(10): p. 2625-2643.
[20] Rajaeifar, M.A., R. Abdi, and M. Tabatabaei, *Expanded polystyrene waste application for improving biodiesel environmental performance parameters from life cycle assessment point of view.* Renewable and Sustainable Energy Reviews, 2017. **74**: p. 278-298.
[21] Gu, F., P. Hall, and N. Miles, *Development of composites based on recycled polypropylene for injection moulding automobile parts using hierarchical clustering analysis and principal component estimate.* Journal of Cleaner Production, 2016. **137**: p. 632-643.
[22] Al-Hadithi, A.I. and N.N. Hilal, *The possibility of enhancing some properties of self-compacting concrete by adding waste plastic fibers.* Journal of Building Engineering, 2016. **8**: p. 20-28.

[23] Muise, I., et al., *Attitudes to the recovery and recycling of agricultural plastics waste: A case study of Nova Scotia, Canada*. Resources, Conservation and Recycling, 2016. **109**: p. 137-145.
[24] Kreiger, M., et al., *Life cycle analysis of distributed recycling of post-consumer high density polyethylene for 3-D printing filament*. Journal of Cleaner Production, 2014. **70**: p. 90-96.
[25] Ishaiba, A.A., *Mechanical Properties of Concrete Using Recycled Plastic*. 2015, The Islamic University-Gaza.
[26] Yin, S., et al., *Use of macro plastic fibres in concrete: a review*. Construction and Building Materials, 2015. **93**: p. 180-188.
[27] Frigione, M., *Recycling of PET bottles as fine aggregate in concrete*. Waste management, 2010. **30**(6): p. 1101-1106.
[28] Ling, T.-C. and C.-S. Poon, *A comparative study on the feasible use of recycled beverage and CRT funnel glass as fine aggregate in cement mortar*. Journal of cleaner production, 2012. **29**: p. 46-52.
[29] Ferreira, L., J. de Brito, and N. Saikia, *Influence of curing conditions on the mechanical performance of concrete containing recycled plastic aggregate*. Construction and Building Materials, 2012. **36**: p. 196-204.
[30] Vanitha, S., V. Natarajan, and M. Praba, *Utilisation of waste plastics as a partial replacement of coarse aggregate in concrete blocks*. Indian Journal of Science and Technology, 2015. **8**(12).
[31] Tang, W., Y. Lo, and A. Nadeem, *Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete*. Cement and Concrete Composites, 2008. **30**(5): p. 403-409.
[32] Alhozaimy, A. and M. Shannag, *Performance of concretes reinforced with recycled plastic fibres*. Magazine of Concrete Research, 2009. **61**(4): p. 293-298.
[33] Kim, S.B., et al., *Material and structural performance evaluation of recycled PET fiber reinforced concrete*. Cement and concrete composites, 2010. **32**(3): p. 232-240.
[34] Asokan, P., M. Osmani, and A.D. Price, *Improvement of the mechanical properties of glass fibre reinforced plastic waste powder filled concrete*. Construction and Building Materials, 2010. **24**(4): p. 448-460.
[35] Ramadevi, K. and R. Manju, *Experimental investigation on the properties of concrete with plastic PET (bottle) fibres as fine aggregates*. International journal of emerging technology and advanced engineering, 2012. **2**(6): p. 42-46.
[36] Rai, B., et al., *Study of waste plastic mix concrete with plasticizer*. ISRN Civil Engineering, 2012. **2012**.
[37] Osmani, M. and A. Pappu, *An assessment of the compressive strength of glass reinforced plastic waste filled concrete for potential applications in construction*. Concrete Research Letters, 2010. **1**(1): p. 1-5.
[38] Ben Fraj, A., M. Kismi, and P. Mounanga, *Valorization of coarse rigid polyurethane foam waste in lightweight aggregate concrete*. Construction and Building Materials, 2010. **24**(6): p. 1069-1077.
[39] Nili, M. and V. Afroughsabet, *The effects of silica fume and polypropylene fibers on the impact resistance and mechanical properties of concrete*. Construction and Building Materials, 2010. **24**(6): p. 927-933.
[40] Yin, S., et al., *Fiber preparation and mechanical properties of recycled polypropylene for reinforcing concrete*. Journal of Applied Polymer Science, 2015. **132**(16).
[41] Kan, A. and R. Demirboğa, *A new technique of processing for waste-expanded polystyrene foams as aggregates*. Journal of Materials Processing Technology, 2009. **209**(6): p. 2994-3000.

[42] Choi, Y.W., et al., *Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles.* Construction and Building Materials, 2009. **23**(8): p. 2829-2835.

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