Eco-friendly Concrete Using Waste Plastic Bottles as Aggregate: A Case Study from Oman

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Abstract

Waste plastic bottles (WPB) (polyethylene terephthalate (PET)) type are used widely for water storage and eventually become environmental burden. This study investigated an innovative application of the WPB to partially replace the fine aggregate in concrete nonstructural element. This research evaluated the effect of plastic content on concrete mechanical and physical properties. The WPBs were ground into < 5 mm in size equal to the fine aggregate size. Therefore, different percentages of WPB were used namely 10, 20 and 30%. The results revealed that 20% of the WPB showed the best results to produce light weight concrete. The compressive strength was reduced by 20% only with 20% of WPB which it declined by 42% with higher WPB content. Moreover, concrete with 20% of WPB content achieved ultrasonic pulse velocity (UPV) of 3 km/s which indicated a satisfactory level of concrete integrity. This indeed clearly indicated that the plastic content should be carefully selected before full applications. This study suggested that each cubic meter of concrete can accommodate around 100 kg of WPB. Indeed, that will reduce the pressure on landfills and the environment by having this innovative application.

Keywords: Recycling; Concrete; PET; Environment

1 Introduction

The word plastic is derived from "pliable" which means "easily shaped". Plastic is basically polymers or monomers with long chains. It was successfully synthesized since the end of the nineteen century (Gilbert et al., 2017). Nowadays, the plastic become a prominent content of many items in our daily life (e.g. plastic bags, furniture, cars, toys etc.). Annual world production of plastic reached 370 Mt tons in 2019 and expected to reach 800 Mt by 2035 and 1600 Mt by 2050 (Alagha et al., 2022; Ali et al., 2021). Globally, around 72% of plastic is wasted (40% landfills, 34% released to the environment), 14% incinerated while only 14% is recycled (Evode et al., 2021). The sea receives annually 8.3 Mt which cause death of 1.5 million marine animal per year. The plastic is decomposed into small particles called microplastic which transferred easily to different receptors (animal, human beings) though air, water, and food chains. Recent studies revealed that microplastics presents in table salt, sugar, honey, bottled water etc. (Cooc et al., 2020). That alarmed the researchers and decision makers to implement new methods to mitigate the effect of the plastic in our daily life. Furthermore, plastic manufacturing processes released wide variety of harmful gases to the atmosphere including hydrogen cyanide, carbon monoxide, dioxins, nitrogen oxides (Ali et al., 2021)

Plastic can be categorized into different types: polyethylene (PE), polyvinyl chloride (PV), polystyrene (PS), High density polyethylene (HDPE), polyethylene terephthalate (PET), polypropylene (PP) and polyurethane (PU) (Evode et al., 2021; Ali et al.,2021). PET and PU represent 18% of the total plastic production. PET is produced from fossil feedstock since 1940s and used mainly for manufacturing of plastic bottles. Most of the PET end up to the environment.

Plastic wastes can be used effectively in different construction materials such as aggregate, insulator, or filler compound, road pavement. Lightweight concrete can be produced by replacing aggregate content with light weight material. Plastic became the best candidate due to its abundance and good mechanical properties. Many studies reported the efficacy of reducing unit weight of the concrete by partially replacing the sand or aggregate contents by plastic (Almeshala et al., 2020; Ayewera & Adesina, 2020). The lightweight concrete can provide better heat insulation features, more cost effective and less manpower. Moreover, using plastic in construction materials partially will reduce sand consumption and preserve the natural resources. Plastic application should be limited to non-structural elements as the compressive strength is reduced significantly. That mainly attributed to vulnerable bonding between plastic and cement and small unit weight of plastic. Nonetheless, studies showed that using plastic fiber in concrete reduce shrinkage effects and improved the thermal properties of the cementitious materials (Ochi et al, 2007; Silva et al., 2005). Using plastic content as base and subbase materials in road construction showed betterment in the stiffness, shear and bearing capacity of the road (Benson & Khire, 1994).

Gulf Cooperation Council (GCC) countries generate nearly 11.9 Mt of municipal solid waste(MSW), of which 25±15 % is recycled (Alagha, et al., 2022). In Particular, United Arab Emirates (UAE) accounted for higher percentage (37%) of MSW followed by Kuwait and Saudia Arabia with 20%, then Oman 17% (2 Mt/year) and the lowest Qatar (10%) and Bahrin 8% (Beah, 2022 and Alagha et al., 2022). The plastic waste represents around 14% of the total generated MSW. In Qatar, around 14% of plastic waste is recovered of which 40% is recycled (8.6 kt) the remaining either discarded to landfills or incinerated in open area (Alagha et al., 2022).

GCC countries have few initiatives to mitigate the effects of plastic waste by reducing the waste production and promoting recycling practices. In Oman, the government recently banned the single-use plastic shopping bags and promote the use of textile reusable bags (Environment Authority, 2022). That indeed is expected to reduce the plastic waste generation significantly. In Saudi Arabia, recycling and energy recovery from plastic waste is still underdevelopment with up to 15% of plastic waste recovery (Alagha et al., 2022).

The main aim of this study was to find ecofriendly solution for wasted plastic bottles (WPB) by using in concrete blocks with partial replacement of the fine aggregate. This is expected to have dual benefits to protecting the environment from hazardous materials and secondly protecting the natural sources. WPBs were collected and shredded to the size range of the fine aggregated and used in concrete block with different ratios. Different tests were conducted to evaluate the effect of the plastic content on the mechanical and physical properties of the concrete. In connection to this, the current study also provided a data related to the plastic consumption rate per capita per day in

Oman based on field study with 70 participants over 4 weeks. It is suggested that the outcomes of this study will trigger the research in this area and provide more insights on plastic waste management using ecofriendly technology.

2 Methodologies

The plastic water bottles were collected from homes with different sizes 250 ml to 500 ml. The bottle caps and plastic labels were removed. Then the bottles were sent to be shredded using shredding machine. The shredded particle sizes less than 4.7 mm equivalent to the size of the fine aggregate. Three different plastic percentages (10, 20 and 30%) were used in this study to partially replace the fine aggregate. Control sample without plastic content was examined to observe the effect of the plastic contents

2.1 Concrete Mix Design

The concrete mix was designed as per the Department of Environment (DOE) method. The design outputs summarized in the table below (Table 1). The type of cement used is ordinary Portland cement (OPC), crushed aggregate. The sieving analysis was performed to assure aggregate fit within the range of coarse aggregate (20 mm to 10 mm) and fine aggregate (4.75 mm to 150 micron).

Table 1: Concrete mix design as per DOE

Parameter	Value	Parameter	Value
Target mean strength N/mm^2	36.68	Coarse aggregate (kg/m^3)	505
Water cement ratio	0.47	Fine aggregate (kg/m^3)	1238
Cement (kg/m^3)	447		

2.2 Mechanical and Physical Properties of the Concrete

Different tests were conducted to evaluate mechanical and physical properties of the concrete with and without plastic content. To evaluate the workability of the concrete slump test was performed as per the standard method (BS 1881: Part 102). The mechanical properties were evaluated by conducting compressive strength test (BS 1881: Part 116:1983) (Brand ELE International ADR Touch Mod:36-3280/01). The cube sizes 100x100x100 mm. The curing time of the concrete was 7 and 28 days in which the compressive strength was conducted. Ultrasonic is non-destructive test performed to evaluate the integrity of the hardened concrete (Brand MATEST Mod:C372N). The velocity is calculated by dividing the length of the specimen by the required time to pass a sound wave through the specimen.

2.3 Waste Plastic Bottle Field Survey

Field quantification of the waste plastic bottle (WPB) which are used for water storage (200 to 500 ml) was performed over 4 weeks. The number of the family involve in this study was 12 families with total number of 69 person. The WPB is categorized as the polyethylene terephthalate (PET). The number of WPB generated by each family were quantified and the weight is measured. The generation rate was calculated as kg/capita/day.

3 Results and Discussion

3.1 Waste Plastic Bottle (WPB) Survey

The table below showed the details of the field survey (Table 2). The total production of the plastic bottle from the participants was 67143.5 g over 28 days equals 0.035 kg/capita/day.

Table 2: The plastic water bottle production involving 12 families (69 person) over four weeks (28 day) in Muscat, Oman

Sr. No	No. Member	No. Bottles	Size of the bottle (ml)	Weight / bottle (g)	Total weight (g)
1	7	410	500	11.5	4715
2	5	299	500	11.5	3438.5
3	7	760	200	8.5	6460
4	4	111	250	10	1110
5	2	224	250	10	2240
6	9	1440	250	10	14400
7	7	924	250	10	9240
8	5	380	250	10	3800
9	7	255	250	10	2550
10	5	695	250	10	6950
11	7	816	250	10	8160
12	4	408	250	10	4080
total	69				67143.5

3.2 Effects of Plastic Content on the Mechanical and Physical Properties of the Concrete

The concrete fresh mix was tested for the workability using slump test as an indicator. The results revealed that the plastic content reduced the workability of the concrete (Figure 1). That might be attributed to lessening of the homogeneity of the concrete due to plastic addition. Similar observation was reported in other studies (Akinyele et al., 2018; Almeshal et al., 2020; Mustafa et al., 2019).

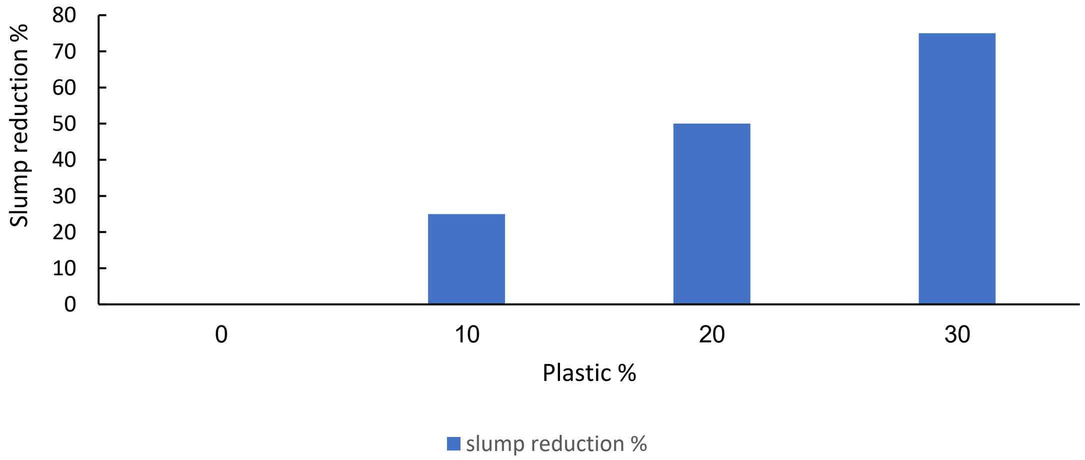

Fig. 1: The effect of the plastic percentage (replacing fine aggregate) on workability of concrete (slump value)

The result compressive strength of the casted cubes with different plastic contents were tested for 7 and 28 days. The results revealed that the plastic contents are reducing the compressive strength of the concrete (Figures 2 & 3). The compressive strength was reduced by 20% with plastic content of 20% while reached 42% with 30% of replacement. These finding came in line with what reported by (Almeshal et al. 2020). This concluded that, the optimum percentage of replacement is 20%. The observed reduction in the compressive strength is mainly attributed to the reduction in the bulk density of the specimen. Moreover, the plastic at high content will lose the bonding with cement and reduce the integrity of the specimen which clearly reflected by Ultrasonic pulse velocity results (Figure 4). The integrity of the concrete was affected positively by the plastic content of 20% with corresponding UPV of 3.1 km/s compared to 2.6 km/s with zero plastic content. That might be attributed to role of small particles of plastic acting as a filler material. In general, values greater than or equal to 3 km/s indicate satisfactory level of concrete integrity.

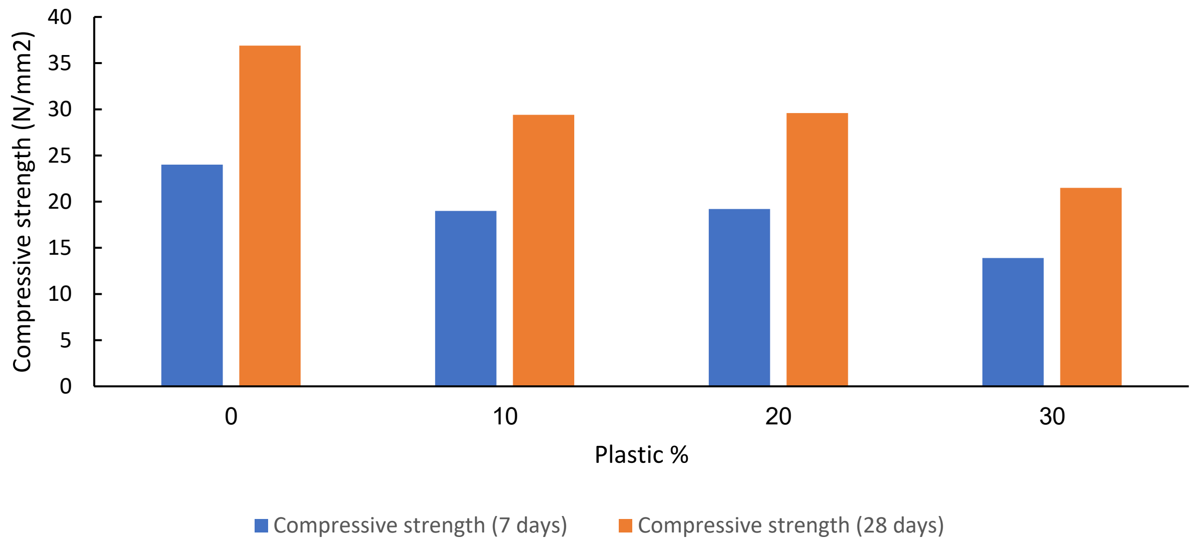

Fig. 2: The effect of the plastic percentages (replacing fine aggregate) on the concrete compressive strength (N/mm^2) after 7 and 28 days

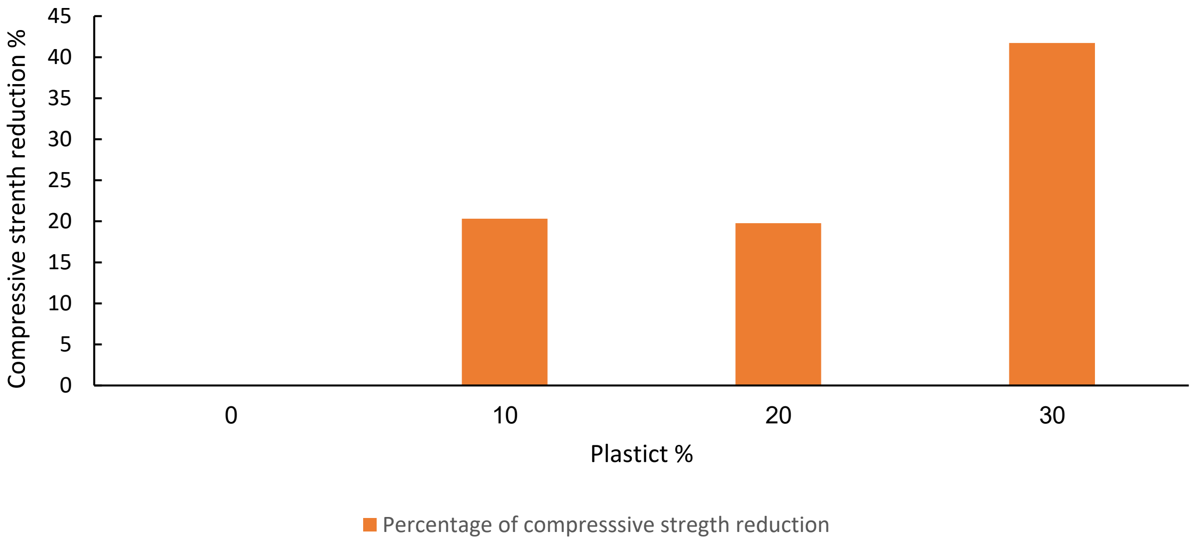

Fig. 3: Reduction on the compressive strength due to plastic percentages after 28 days

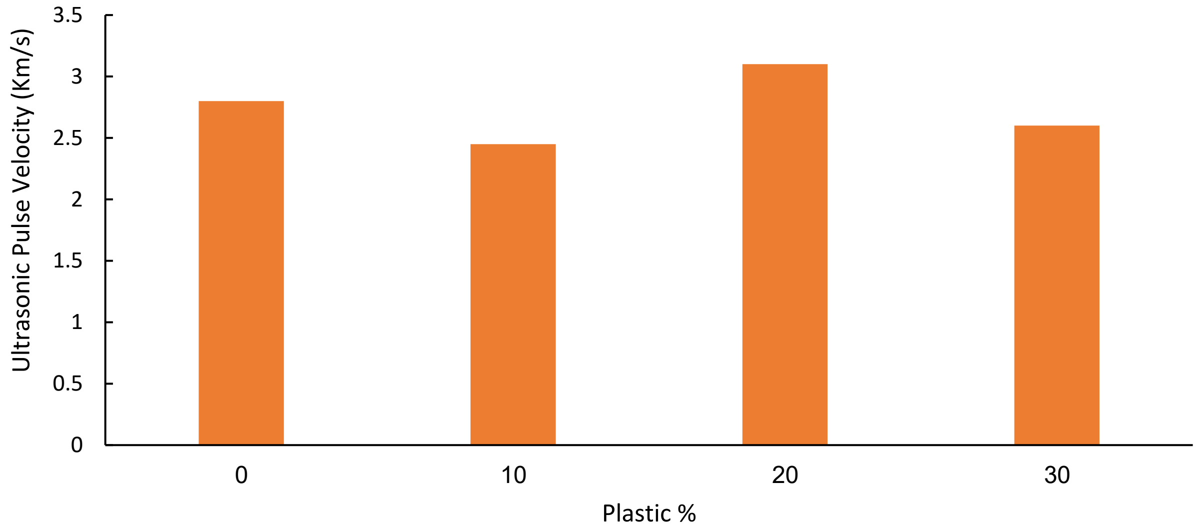

Fig. 4: Ultrasonic pulse velocity (km/s) for different plastic percentages

4 Conclusion

This study concluded that using waste plastic bottles in non-structural concrete (lightweight concrete) was successfully achieved. The optimum plastic content was 20% in partial replacement of fine aggregate. The compressive strength of the produced lightweight block was 30 N/mm^2 compared to 37 N/mm^2 of the control mix (0% plastic). That being said, more investigation is required to address the feasibility of this option. Indeed, using WPB in construction will be reduced tremendously the land size required for landfills and will mitigate the environmental risks associated with plastic waste. This study suggested that each cubic meter of light weigh concrete could accommodate 200 kg of plastic waste.

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