Performance of Sustainable Concrete Containing HDPE Plastic Wastes as Coarse Aggregate: Minor Review

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Abstract. Many experimental studies had made by the researchers to investigate the properties of concrete with different types of plastic wastes as coarse aggregate or as fibres. This research focuses on the studies dealing with High Density Polyethylene HDPE plastic type as coarse aggregate in concrete and making a summary of the most important findings from these studies. All the experimental works stated in these studies showed a decrease in flexural strength, splitting strength and flexural strength. The results also showed that there is a clear decrease in the thermal conductivity which leads to improve thermal insulation of concrete.

1. Introduction
The practice of industrial ecology needs to predict a comprehensible approach. It is simply means that the remnant products of any industry should be recycled as a replacement for virgin raw of another industry, in this way the environmental impact of each industry can be reduced [1].

Building industries especially concrete industry is the most influencing factor that impact the environment. So, recently there is a great interest in the expansion of sustainable issues of the construction, that lead to different materials which may be used instead of cement and aggregate [2]. Plastic products thrown after the first use causing the generation of plastic wastes which are not biodegradable and un reactive to the natural environment, thus these products persist for centuries causing toxic components into the air, water and soil [3].

From above, it is clear that there are two problems. The first is the production of new materials to be used in concrete as a cementitious or raw materials. The second is the disposal of the plastic wastes[4]. Consequently one of the viable solution to eliminate the plastic waste problem is by reusing these wastes in the production of concrete due to the benefits that can be achieved on the environmental and economical levels [5].

The plastics were classified as polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), Polyvinyl chloride (PVC), Polypropylene (PP), Polystyrene (PS) and other resins [6]. Table 1 illustrates the classification of the plastic types and their uses [7].

Many researchers study the use of different types of recycled plastic in concrete, either as aggregate or as fibres. This paper provides a new review of the few existing researches on using high-density polyethylene (HDPE) plastic type wastes as coarse aggregate in the concrete and their influence on its physical and mechanical properties which forms its final performance.
Table 1. Classification of the Plastic Types and their Uses.

| ITEM | Short Name | Scientific Name | Description | Used in |
|------|------------|-----------------|-------------|---------|
| 1    | PET        | Polyethylene terephthalate | Tough plastic | Water bottles |
| 2    | HDPE       | High density polyethylene | Usually white or colored, very common plastic | Carry bags, food container, etc. |
| 3    | LDPE       | Low density polyethylene | Soft, flexible plastic. | Carry bags |
| 4    | PVC        | Polyvinyl chloride | Hard rigid plastic | Pipes, cables, etc. |
| 5    | PP         | Polypropylene | Hard but flexible Plastic | Medicine bottles, etc. |
| 6    | PS         | Polystyrene | Rigid, brittle plastic. | ice-cream containers, cups, etc. |
| 7    | O          | Others | --- | Thermoset plastic, melamine, nylon, etc. |

2. Physical Properties

2.1. Slump

The main property of fresh concrete which determines its ability to be placed, consolidated and finished without any segregation is workability. The slump cone test, compacting factor test and vebe test are the major tests which can be used to measure the concrete workability [8] [9].

Gu et al.; Sharma et al. and Al meshal et al. [6], [9], [10] reviewed many experimental studies that investigated the use of different types of plastic wastes to concrete as aggregate. They showed the variance of the effect of adding plastic wastes particles on workability. Most of these studies in their reviews displayed a decreasing in slump with the increase in plastic aggregate ratio while some authors found that there was no important influence on the slump results. However, few studies of these reviews indicated that the slump increased when the plastic aggregate was added leading to improve the workability. They concluded that the addition of plastic aggregate leads to lower slump because of the increasing in the surface area and in irregular shape of plastic concrete particles [6].

Al Bakri et al. [8] added trash plastic bags which were used as HDPE plastic wastes coarse aggregate (PWCA) treated with different temperature degrees in five different composition ratios with natural crushed stone. The workability of concrete with 100% HDPE PWCA is lower by about 76.4% compared to concrete with 100% natural stone. This effect on workability is attributed to the smooth surface of HDPE PWCA particles.

Hussein et al.[4] investigated the influence of adding different percentages of plastic boxes (which are classified as HDPE plastic type) as coarse aggregate in different age of concrete and find the slump decreased clearly and the concrete mix become stiffer with increase HDPE PWCA ratio. Jonbi et al. [11] studied the difference between using different substituting levels of two types of plastic wastes polypropylene (PP) and high-density polyethylene (HDPE) as PWCA. They indicated that the decrease of slump with plastic percentage increase is due to the non-uniformity in the plastic particle shape which caused low fluidity. Table 2 states the decrease in slump with the increase of HDPE PWCA amount for study [4] and [12].

Khalil and Al Obeidy[12] studied the use of progressive ratios of HDPE PWCA to concrete containing 15% glass powder. The workability increased slightly with HDPE PWCA ratio increment because of the very low absorption of HDPE PWCA compared with natural coarse aggregate.
Table 2. Decrease of Slump with Increase in HDPE PCWA Percentage in [4], [11].

| %HDPE PWCA | Slump (mm) | %HDPE PWCA | Slump (mm) |
|------------|------------|------------|------------|
| 0          | 60         | 15         | 75         |
| 20         | 40         | 20         | 48         |
| 40         | 30         | 25         | 20         |
| 60         | 20         |            |            |
| 80         | 10         |            |            |

2.2 Unit Weight and Density

Gu et al.; Sharma et al. and Al meshal et al. [6], [9], [10] indicated the decrease of unit weight and fresh/dry density due to the low density of plastic wastes aggregate. Generally, the addition of plastic as aggregate causes a reduction in unit weight whatever the type and size of the amount added [10].

Al Bakri et al. [8] found that the density of concrete containing HDPE PWCA is between 1400 and 1550 kg/m³. Shanmugapriya and Santhi [13] investigated the effect of adding HDPE PWCA in different ratios and stated in their conclusion that HDPE addition as partial replacement of coarse aggregate causes a reduction in the overall unit weight of concrete. Khalil and Al Obeidy [12] detailed the decrease of fresh and dry density of concrete with the increase of HDPE PWCA ratio and illustrate that the decrease is due to the low density of HDPE plastic aggregate (0.949 kg/m³) in comparison with natural aggregate density (1.715 kg/m³). Their results show that the fresh density with different plastic ratios ranged from 2484.6 kg/m³ for concrete containing (15% HDPE PWCA) as volumetric replacement to natural coarse aggregate and it is 2055.5 kg/m³ for concrete containing (100% HDPE PWCA) as volumetric replacement to natural coarse aggregate while the oven dry density ranged from 2341.9 kg/m³ for concrete containing (15% HDPE PWCA) as volumetric replacement to natural coarse aggregate and it is 1862.4 kg/m³ for concrete containing (100% HDPE PWCA).

Zasiah et al. [5] investigated in their research the use of polyethylene terephthalate (PET) PWCA and HDPE PCWA as partial replacement of natural coarse aggregate separately and together. They found that the fresh density of concrete decreased by about 4% from control specimen and about 2310 kg/m³ for 10% HDPE PWCA. Hussein et al. [4] found that the utilization of HDPE PWCA caused a reduction in weight of samples of about 26.5% and the dry density of samples studied were 1.440 kg/cm³-1.840 kg/cm³ that means they exceeded the range of lightweight concrete.

Belmokaddem et al. [3] investigated the properties of concrete containing different types of plastic as fine and coarse aggregate one of them HDPE in three levels of ratios. They found that the density of HDPE aggregate was 0.95 gm/m³ and their results of dry and fresh density exceeded the limit of lightweight concrete when the HDPE PWCA rather less than 75%. They associated these results with the same results of another researches and emphasized on their conclusion on the fact that the partial replacement of any plastic aggregate produce lower fresh and hardened density concrete.

2.3. Water Absorption and Air Content

Al Bakri et al. [8] classified the HDPE PWCA due to their colours before measuring their water absorption due to the fact that the colour of plastic depends on the pigment when the plastic bags processed. The HDPE PWCA made an obvious difference in their absorption to water (0-7%) compared with natural crushed stone. They presented that the fresh concrete with HDPE PWCA has lower water absorption.

Gu et al. [6] noticed in their review that few researches studied the air content of concrete containing PWCA and most of them stated that the use of PWCA causing increase in the air content due to the fact that natural and plastic aggregate could not sufficiently mixed in the concrete. Their conclusion is that the water absorption and porosity increased with the increase in PWCA. Khalil and Al Obeidy [12] showed that the exciting of HDPE PWCA in concrete increases water absorption because of their fluky and elongation shape which increase the continuous path between pores and leads the...
porosity to increase in addition that the unsuitable compaction due to low density formed more pores. Belmokaddem et al. [3] studied the ultrasonic pulse velocity (UPV) of concrete which is indirectly related to the porosity of concrete. The UPV results show reduction as the PCWA increase and especially for HDPE type which showed more significant decrease than other types of PWCA investigated in this research which means a more increase in the porosity of concrete congaing HDPE PWCA and best acoustic insulation property.

3. Mechanical Properties

3.1. Compressive Strength

Compressive strength is the most important property of concrete that give clear idea about its performance and quality [10]. Sharma et al.; Gu et al. Al Meshal et al. [6], [9], [10] showed in details and plots that all researchers found that the compressive strength decreased when the content of any type of aggregate increased. Al Bakri [8] stated that the concrete strength decreased as HDPE PWCA increase and they found that HDPE PWCA concrete behaviour is not different from that for lightweight concrete contained natural crushed stone. Shanmugapriya and Santhi [13] specimens with different ratios of HDPE PWCA showed a low and descending decrease in compressive strength with age where the specimens of 28 days were very comparative with reference specimens than that of 7 days and 14 days .Zasia et al. [5] showed that the specimens compressive strength of HDPE PWCA gave lower values compared with that for reference one and compared with that containing PET PCWA and PET+HDPE PCWA. Khalil and Al Obeidy [12] represented a clear reduction in compressive strength with the increase of HDPE PCWA content. Hussein et al. [4] tested the compressive strength at 7, 28 and 56 days and found that concrete with 20% and 40% HDPE PWCA are most suitable because they showed a little decrease in compressive strength relative to concrete with 0% HDPE PWCA. Jonbi et al. [11] showed that concrete which with PP PWCA gave higher compressive strength than that with HDPE PWCA and these results are compatible with results obtained by Belmokaddem et al. [3] where they found that specimens with PVC and PP PWCA have compressive strength higher than that of HDPE PWCA.

The major reasons of the decrease in compressive strength adopted by researchers above are:

1. The low bond and adhesive between PWCA and cement paste.
2. The hydrophobic nature of plastic particles which restrict the movement of water and causing less hydration.
3. The natural aggregate is stronger than PWCA and the strength of aggregate forms about three quarter of concrete strength[12].

3.2. Splitting Tensile Strength

Generally, the splitting tensile strength is studied to understand concrete tension behaviour. Usually it is obtained by doing split tensile test which is consider as indirect method to find the tensile strength of concrete[9].

Sharma et al. [9] indicated that inclusion of small amount of PWCA leads the tensile strength to slightly increase while using large amount leads to a decrease in the splitting tensile strength. They presented many additional parameters affecting the strength of concrete which should have more attention by the researchers like, the amount of plastic added, size and shape of plastic particles, the treatment of plastic etc. Gu et al. and Al Meshal et al. [6], [10] concluded that the tensile strength decreased with the use of PWCA due to the same reasons mentioned above about the decrease in the compressive strength. Shanmugapriya and Santhi [13] indicated that the splitting tensile results of concrete with HDPE PWCA at 7 and 14 days age were more than the control specimen which contain natural aggregate without any PWCA substitution and there is proportional increase with the increase of HDPE PWCA content due to the ductile property of HDPE PWCA. In the 28 days the results showed a clear reduction due to the weak bond of HDPE PWCA with the cement paste and free water on their surfaces. Zasia et al. [5] showed that the splitting strength of specimens containing HDPE PWCA were lower than that of control specimens or that containing PET PWCA.

Khalil and Al Obeidy [12] stated that the inclusion of HDPE PWCA in concrete gradually decrease the splitting strength due the same reason mentioned for compressive strength reduction. Hussein et al. [4] experimental study showed clear decrease in splitting tensile strength with the increase of HDPE PWCA amount ratio.
3.3. Flexural Strength
Flexural strength or modulus of rupture is the deformation resistance ability of a material under flexural load. Usually the unreinforced specimen used for determining this property is rectangular cross section and it is bent until failure using three or four-point load [10].

Gu et al.; Sharma et al. and Al Meshal et al. [6], [9], [10] represented studies which their results show a clear decrease in flexural strength when PWCA added. Al Bakri [8] experimental study showed very small variation of specimens contained different percentages of HDPE PWCA with reference specimens contained only natural aggregates. Shanmugapriya and Santhi [13] showed a superior performance in the flexural strength of samples contained HDPE PWCA compared with that contained only natural coarse aggregate and the mix with 15% HDPE PWCA gave better flexural test results than that contained 10% and 20%.

Khalil and Al Obeidy [12] experimental test results showed a clear linear decrease in flexural strength with the increase of HDPE PWCA content. They referred this decrease to the same reasons of compressive and splitting strength decrease.

3.4. Modulus of Elasticity
Aggregate plays an essential role in concrete mechanical properties. Most of researches showed that any form of plastic decreases the modulus of elasticity of concrete. Gu et al.; Sharma et al. and Al Meshal et al. [6], [9], [10] showed a decrease in modules of elasticity with the increase in plastic waste substitution due to the decrease in compressive strength and many other parameters affect the in elastic modulus.

4. Other Properties
4.1. Thermal Conductivity
Thermal conductivity (k-value) is a crucial factor in concrete when the amount of heat transfer is considered through conduction. When thermal conductivity is low the energy consumption and heat transfer are decreased. The ordinary method used for measuring thermal conductivity are the steady state for homogeneous materials and transient method for heterogeneous material with a rather moisture content [10].

Gu et al.; Sharma et al. and Al meshal et al. [6], [9], [10] discussed many researches which studied the thermal conductivity of concrete containing different types of PWCA and they concluded that the adding PWCA decrease thermal conductivity. Khalil and Al Obeidy [12] tested the specimens at 60 days and found a notable decrease in thermal conductivity factor with the increase in HDPE PWCA content because of the big numbers of pores in the microstructure of concrete containing HDPE PWCA and the high porosity that affect the thermal conductivity factor. Belmokaddem et al. [3] showed a clear reduction in thermal conductivity of concrete with HDPE PWCA compared with reference concrete and refer that HDPE PWCA improved the thermal insulation of concrete.

4.2 Chloride Migration
The chloride migration of concrete is influenced by porosity, permeability and water absorption. Chloride ion penetration is increased the voids number increased [10]. Sharma et al. and Al Mashel et al. [9], [10] stated that the curing of concrete samples congaing any type of PWCA affecting chloride penetration where that cured in laboratory environment have the lowest chloride penetration followed by specimens cured in outdoor environment and in wet chamber respectively. Shanmugapriya and Santhi [13] illustrated the standard value of chloride ion penetration of ASTM C1202 and showed that their specimens of 28 days with HDPE PWCA lies in moderate level of 2000 -4000 coulombs.

5. Conclusions
1. Concrete containing HDPE PWCA has lower workability than that with natural aggregate.
2. The inclusion of plastic as a replacement to aggregate in concrete causes a reduction in unit weight and density of concrete whatever the type, shape, size and content of HDPE PWCA added.
3. The air content of concrete containing HDPE PWCA is increased which leads the water absorption is increased.
4. The compressive strength, splitting tensile strength, flexural strength and modulus of elasticity decrease with the increase in HDPE PWCA content.
5. The increase of HDPE PWCA in concrete causes a decrease in thermal conductivity which leads to the improvement of thermal insulation of concrete.
6. Chloride migration higher in concrete containing HDPE PWCA than that with natural coarse aggregate.
7. All studies available for plastic waste aggregate in general and HDPE plastic aggregate type in practical investigated the physical and mechanical properties of concrete and there is no real effort to study structural performance of these types of concrete.

6. References
[1] Mehta P K and Monteiro P J 2017 Concrete microstructure, properties and materials Mc Graw Hill.
[2] Almayah A A, Abbas A M and Saadoon A S 2019 Revision Study of Green Concrete. Basrah Journal for Engineering Science 19 33–38
[3] Belmokaddem M, Mahi A, Senhadji Y and Pekmezci B Y 2020 Mechanical and physical properties and morphology of concrete containing plastic waste as aggregate Constr. Build. Mater. 257 119559
[4] Hussein A A, Breese M K, Jassam S H and Heil S M 2018 Strength Properties of Concrete Including Waste Plastic Boxes IOP Conf. Ser. Mater. Sci. Eng. 454
[5] Tafheem Z, Rakib R I, Esharuhullah M D, Alam S M R and Islam M. M 2018 Experimental investigation on the properties of concrete containing post-consumer plastic waste as coarse aggregate replacement J. Mater. Eng. Struct. 5 23–31
[6] Gu L and Ozbakkaloglu T 2016 Use of recycled plastics in concrete: A critical review,” Waste Manag. 51 19–42
[7] Feisl N, Al-Obeidy M, By S, Wasan P and Khalil I Some Properties of Polymer Modified Sustainable Concrete.”
[8] Al Bakri A M.M., S. T. Mohammad, A. . Rafiza, and Y. Zarine, “Page_339,” vol. 1, no. 7, pp. 340–345, 2011, [Online]. Available: papers3://publication/uuid/5B2D2C6C-726D-4752-9DDF-C8D564A40868.
[9] Sharma R and Bansal P P 2016 Use of different forms of waste plastic in concrete - A review,” J. Clean. Prod. 112 473–482
[10] Almeshal I, Tayeh B A, Alyousef Alabduljabbar R H, Mohamed A M, and Alaskar A 2020 Use of recycled plastic as fine aggregate in cementitious composites: A review,” Constr. Build. Mater. 253 119146
[11] Jonbi J, Meutia W, Tjahjani A R I, Firdaus A, and Romdon S 2019 Mechanical properties of polypropylene plastic waste usage and high-density polyethylene in concrete,” IOP Conf. Ser. Mater. Sci. Eng. 620
[12] Khalil W and Al Obeidy N 2018 Some properties of sustainable concrete containing two environmental wastes MATEC Web Conf. 162
[13] Shanmugapriya M and Helen Santhi M 2017 Strength and Chloride Permeable Properties of Concrete with High Density Polyethylene Wastes Int. J. Chem. Sci., 15