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Influence of Recycled Waste High Density Polyethylene Plastic Aggregate on the Physico-Chemical and Mechanical Properties of Concrete

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Abstract**—***Utilisation of waste plastic materials as aggregates in concrete manufacturing could be a partial solution to the environmental and ecological challenges associated with the use and disposal of plastics. This study examines the possibility of using waste High Density Polyethylene (HDPE) as a partial replacement for coarse aggregate in concrete formulation at various plastic compositions (0%, 2%, 4%, 6% and 8% by weight of the coarse aggregate). Particle size distribution (PSD) and specific gravity tests were conducted for the plastic aggregates. The influence of the waste HDPE on the fresh and hardened state properties of the concrete, the workability, compressive and flexural strengths were investigated. The effect of water on the compressive strength of the composite was also determined for the various compositions. Results of various tests suggest that workability of the fresh concrete decreased with increasing plastic content, the compressive strength of the concrete decreased appreciably with increase in the plastic content and was found to be lower than normal concrete. The 28th day flexural strength decrease marginally with increase in plastic content in the concrete. Also the mass of water absorbed by the concrete samples increased with increasing plastic content. Despite the effects of waste HDPE on the various properties of the composite, results were all found to be within acceptable limits. Thus waste HDPE materials could be considered for use in formulation of concrete*.

I. INTRODUCTION

In Ghana lack of sustainable waste management techniques by the local authorities has led to most of the plastic waste not collected or disposed of properly in an appropriate manner. In most towns and cities the waste plastics are thrown into municipal waste collection centers from where it is collected by the local authorities for further disposal into landfills and dumpsites. However, not all of these wastes gets collected and transported to the final dumpsites. As a result the waste plastic can pose serious problems which include contributing to blockage of drains and gutters which consequently cause flooding, release of toxic gases into atmosphere when they are burnt, and choking of livestock and aquatic species when they are ingested as food. Waste plastic can also serve as breeding grounds for mosquitoes when the plastic materials are filled with rainwater. Thus waste plastics pose disposal and ecological problems as they take several years to degrade.

Available options for dealing with plastic waste are recycling, reduction, reuse of plastics and recovering. In developed countries, recycling technology has been the solution of choice but in developing countries, like Ghana it may not be economically viable since it is heavily capital intensive (UNEP, 2009).

Ghana and many developing countries are currently experiencing rapid urbanization and industrialization and as a result a lot of infrastructure developments are going on in these countries. However, these developments are plagued with problems such as acute shortage of construction materials, sky rocketing prices of construction materials and increased generation of waste. Plastic is one major component of Municipal Solid Waste (MSW) which is becoming a major research issue for its possible use in concrete. There have been successful or partial replacement of aggregates or filler components of concrete with industrial waste such as fly ash and wood chips. (Bignozzi *et al.,* 2000). Waste plastics of various types can be used as partial replacements of aggregates in the manufacturing of concrete (Mostafizur *et al.,* 2012). For instance Expanded polystyrene (EPS) based waste, High Density Polyethylene (HDPE), Polyethylene Terephthalate (PET) waste bottles, Polypropylene fibers and Polyethylene bags have all been used in different forms by researchers in concrete. In this study, high density polyethylene bottles which forms 19% of waste plastic in municipal solid waste (Sarker, 2010) was shredded into flakes and used as a partial replacement of coarse aggregate in concrete.

II. MATERIALS AND METHODS

A. Cement

Ordinary Portland limestone cement manufactured by Ghacem CEM II/BL 32.5R was used for moulding the cubes and beams for all the concrete mixes. The cement was of uniform grey colour, free from any hydrated lumps and was bought from a local vendor. Chemical composition of the cement as determined using X-ray fluorescence method and some other properties of the cement are shown in Tables 1 and 2 respectively.

TABLE 1. Chemical composition of Portland limestone cement.

Constituent	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	SO_3	Cl	L.O.I
Dimension, %	28.79	6.78	1.81	4.07	54.17	0.28	2.69	0.04	0.1	0.15	6.34	< 0.0006	3.31

TABLE 2. Properties of the cement.

Property	Results
Normal consistency, %	27.5
Initial setting time, min	135
Final setting time, min	240
28-days compressive strength, MPa	36.8
Specific gravity	3.16
Blaine fineness, m^2/kg	336

B. *Coarse and Fine Aggregates*

Ordinary pit sand used for the experimental work was procured locally from Fumesua near Kumasi, Ghana. The sand was first dried and passed through a 5mm sieve to remove any roots or debris. Coarse aggregate with maximum size of 19 mm was procured from CONSAR Ghana Ltd. High density Polyethylene (HDPE) bottles identified using its recycled code were collected from the environment and used in the work. The labels on the bottles were removed and the bottles washed, cleaned, dried and cut or shredded into smaller flake sizes manually using table knife and scissors. The shredded HDPE was used to partially replace coarse aggregate in proportions of 2 wt.%, 4 wt.%, 6 wt.% and 8 wt.%. Some properties of the fine aggregates, coarse aggregates and HDPE are presented in Table 3. Particle size distribution of the sand, coarse aggregate and HDPE, as determined by Malest Auto Sieve Shaker is also presented in figure 1. Portable water was used for all the concrete mixes.

TABLE 3. Some properties of the aggregates and HDPE.

Property	Granite	HDPE	Sand
Flakiness index (%)	18	-	–
Elongation index (%)	11	-	–
Aggregate impact value (%)	10	3.91	–
Aggregate crushing value (%)	12	6	–
Los Angeles abrasion value (%)	20.3	4.9	
Ten percent fines	210	–	
Specific gravity	2.64	1.68066	3.89
24h water absorption (%)	0.41	20.594	–
Moisture content (%)	–	–	0.26
Silt test (%)	–	–	4
Fineness modulus	6.57	6.24	2.6

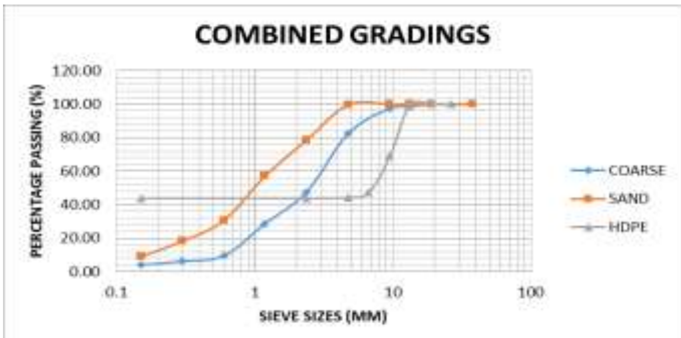

Fig. 1. Particle distribution curve for all aggregates.

C. *Mixing, casting and curing of concrete*

A mix ratio of 1:2:3 was used for all the concrete mixes with a constant water to cement ratio of 0.55, as determined by the slump cone test. After the control mix, the coarse aggregate was partially replaced with HDPE by 2 wt.%, 4 wt.%, 6 wt.% and 8 wt.%.

D. *Test Methods*

The workability of the concrete was assessed using the slump cone test according to methods described in ASTM C143. 150mm×150mm×150mm steel moulds were used to produce the concrete cubes per methods outlined by ASTM C39. After curing the samples in water for 7, 14 and 28 days, their compressive strengths were determined. An ELE Blackhawk flexural strength testing machine was used according to methods described in ASTM 78. A lubricated 100mm×100mm×500mm steel moulds were filled with the fresh concrete and then the specimen covered with wet sack cloth and left for 24hours. After 24hours the specimens were removed from the mould and put into a curing tank containing clean water and left for 28days to determine the modulus of rupture or flexural strength of the concrete. For water absorption, air dried cubes specimens were weighed for their masses and then the dried samples were placed in an oven at a constant temperature of 107^oC for 24 hours to ensure the samples were completely dried with a constant mass. After 24 hours the cube specimens were removed and their masses noted and recorded. The samples were allowed to cool in the laboratory and then immersed in clean water for 24 hours. After 24 hours of immersion in water the specimens were removed and their masses weighed. The percentage absorption of water was then calculated.

III. Results and Discussion

A. *Workability (Slump test)*

Generally, slump height decreased as the percentage replacement of coarse aggregate with waste HDPE increased. A more drastic decrease in the slump was observed with 4% HDPE replacement which was 28mm. A further increase in the plastic waste content yielded no slump as observed from the results obtained for the 6% and 8% HDPE waste replacement respectively which indicates difficulty with which the concrete flows. This means that more water is required to make the concrete workable as HDPE increased in the mix. This trend is due to the fact that the addition of waste plastic fibres obstructs the flow and reduces the workability of the concrete (Prahallada et al., 2013). Slump height of various percentage replacements is shown in figure 2.

B. *Compressive Strength*

Figure 3 is the compressive strength of the concrete mixes. It is observed that the compressive strength increases with increasing curing age for all percentage replacement, a trend which is similar to that of the control. However the incorporation of waste content in the concrete lowers compressive strength of the hardened concrete and reduces further as the percentage replacement increases. The reduction in compressive strength as a result of increasing replacement with waste content may be due to the weak bonds between

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cement mortars and the waste plastic material and also the hydrophobic nature of plastic which restricts hydration of cement (Zainab et al., 2007)

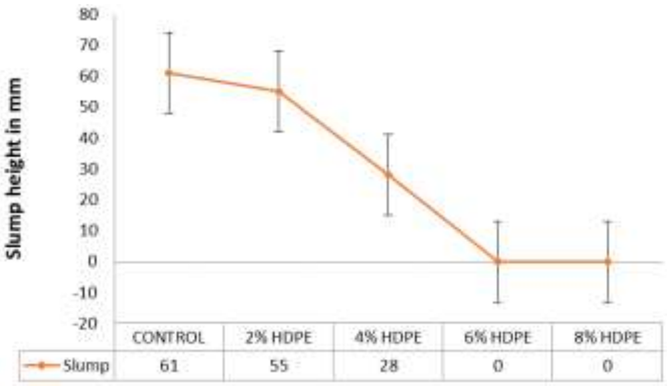

Fig. 2. Slump height of various percentage replacements.

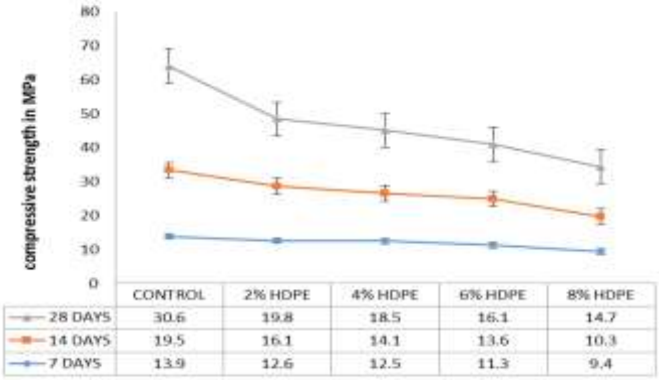

Fig. 3. Compressive strength for all concrete samples.

C. Flexural Strength

Results of flexural strength indicates that the strength decreased systematically with increasing percentage of plastic content but remained the same with 2% and 4% replacement of coarse aggregate with waste HDPE. This may be due to decrease in adhesive strength between the surface of the waste plastic material and the cement paste. The decrease in the flexural strength could be attributed to a decrease in adhesive strength between the surface of waste plastic and the cement paste (Baboo et al. 2012).

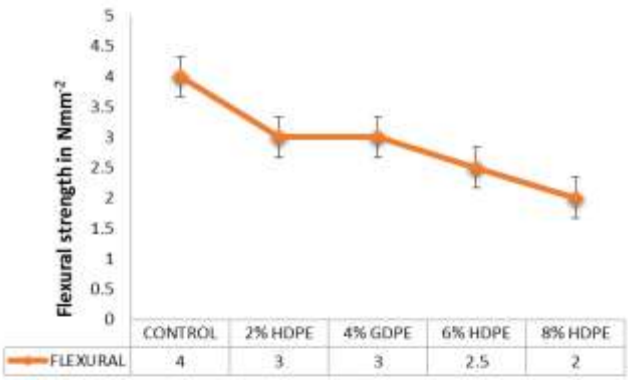

Fig. 4. Flexural strength for all percentage replacements.

D. Water Absorption

The percentage mass of water absorbed by the concrete specimens increased linearly with the increase in waste plastic content with the control concrete absorbing 2.5% whiles 8% HDPE replacement absorbed the most with 3.4%. This could be due to higher waste plastic content in which water occupies the space in the concrete and as it evaporates it leaves voids thus increase the absorption value (Kartina et al. 2010).

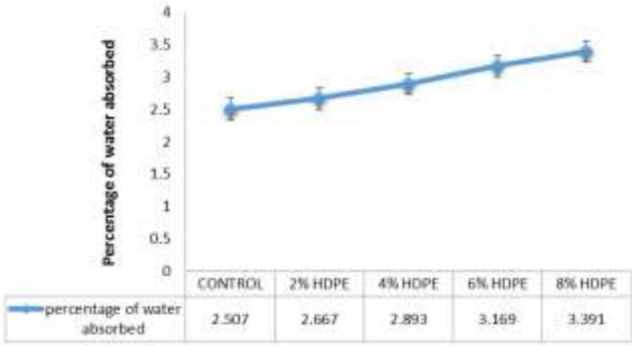

Fig. 5. Percentage mass of water absorbed by concrete samples.

IV. Conclusion

After the preliminary test on the concrete samples the following conclusions were made on waste HDPE as partial replacement in concrete

- Workability of fresh concrete decreased with increase in the percentage of waste plastic content.
- The compressive strength of all the concrete samples increased with increasing curing days. However the compressive strength for the normal concrete was higher than the compressive strength of concrete samples containing HDPE plastic and decreased with increasing plastic content in concrete.
- The flexural strength of the specimens after 28 days decreased marginally with increase in waste plastic content.
- The percentage mass of water absorbed by the concrete samples also increased with increasing plastic content.

From this study it has been identified that the use of waste HDPE as partial replacement of aggregate in concrete has some effects on the properties of the concrete but the results are all within the acceptable strength development properties. Waste HDPE could therefore be used as a cheap alternative to replace aggregate partially in construction especially in the formulation of concrete.

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