Waste Management: Solid, Liquid, Hazardous, Bio-medical and Electronic Waste

PLAS-CRETE: Manufacture of Construction Blocks with shredded PET and HDPE

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ABSTRACT

This project is based on the development, testing and evaluation of lightweight aggregate cementitious products utilizing shredded Polyethylene terephthalate (PET) and High Density Polyethylene (HDPE) from shredded plastic bottles and crates. The innovation for this project is twofold. Firstly, thousands of PET and HDPE plastic materials, particularly plastic bottles, are improperly disposed of each day resulting in large volumes of plastic waste entering and remaining in the natural environment. This has become a solid waste management challenge in Guyana since it is estimated that over 10,000 tonnes of waste plastic are discarded yearly, in Georgetown alone. Secondly, efficient means of re-using waste plastic, particularly PET and HDPE must be found since in developing countries it may not be economically viable based on the volumes of plastic produced, to recycle.

To begin with, plastic is non–biodegradable, thus will exists in the environment for hundreds of years. This means that more plastic waste (PET and HDPE) is entering landfill sites than can be naturally broken down and unless reused or recycled, this material will be subject to costly disposal in a landfill thus contributing to crowding of landfills and further resulting in bouts of spontaneous combustion due to lack of maintenance. More so, in 2005, Guyanese experienced disastrous floods exacerbated in part by drains clogged with PET bottles and other disposable plastic materials. This not only affected our environment negatively but contributed to the degeneration of our natural aesthetics.

In more developed societies, recycling technology has been the solution of choice but in developing countries, like Guyana and other sister Caricom Countries, it may not be economically viable based on the relatively small volumes of plastic produced. Hence we need to determine innovative ways to re-use plastic. It is for this reason the author embarked on using shredded PET and HDPE as aggregates in construction material. With the alteration of mix ratios, compressive strengths ranging from 1000 psi to 3781psi were obtained for the blocks, having been moist cured for 7, 14 and 28 days. These values indicated that the blocks could be used for moderate (1000-1200 psi) and structural light weight concrete (>2500 psi) applications such as floors in high–rise buildings (to reduce support load requirements), and as thermal and sound insulation in walls and roof panels (Kosmatka/PCA).

Keywords: Plas-crete, Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), density, Compressive Strength, Unit Weight.

AIM AND OBJECTIVES

The research aims to reduce environmental pollution caused by the copious build-up of plastic waste, by utilising it in a construction material to create a product of value. Essentially, the objectives of this study were to; make lightweight aggregate blocks, cure them in accordance with the ASTM moist cure method, and compare the mean unit weights and compressive strengths obtained against blocks containing the normal aggregates.

SCOPE

The blocks were produced utilizing stones, shredded Polyethylene terephthalate (PET), High Density Polyethylene (HDPE), sand and Portland cement and of course water. During the research, the unit weight and durability of the lightweight aggregate blocks were compared against that of the normal aggregate blocks containing gravel. PET and HDPE aggregates, 4 -5 mm in diameter replaced stone aggregates, 8 - 10 mm in diameter. The four inch thick specimens were moist cured for 7, 14 and 28 days. The unit weight and failure load measured for each block, were used to calculate density and compressive strength, respectively.

BACKGROUND

The idea of using lightweight aggregates in concrete blocks is not new and is increasingly being researched. Several studies mention the use of plastic as lightweight aggregate in concrete. In 2000, the Chelsea Centre for Recycling and Economic development (CCFRED), University of Massachusetts (1), carried out a research using discarded mixed plastics no. 3-7 as aggregate in concrete blocks. They reported compressive strengths ranging from 230 psi to 1700 psi for 'plascrete' batches (the name of their product) containing a range of sizes and types of waste plastic. These values indicated that plascrete can be used for 'low density' (i.e. insulating) and 'moderate-strength' lightweight concrete' (Kosmatka/PCA, 1990).

In another study done by Ghaly and Gill (2) plastic chips were used as partial replacement of coarse aggregates in concrete mixtures. The testing program was organized to study the effect of adding plastic aggregates to the concrete in order to reduce the density and gain superior deformation qualities and to examine the effect of plastic content and water/cement ratio on the mechanical properties of concrete. Test results demonstrated that plastic aggregates are viable in providing the concrete with a high degree of deformability as compared with regular concrete. This characteristic makes the concrete useful in situations where it will be subjected to harsh weather, such as expansion or contraction, or freeze and thaw.

In their studies, Jo, Park and Park (3) evaluated the mechanical properties of polymer concrete, in particular, polymer concrete made of unsaturated polyester resins from recycled polyethylene terephthalate (PET) plastic waste and recycled concrete aggregates. They found that compared to cement-based concrete, polymer concrete (PC) is stronger and more durable. For this reason, polymer concrete is used in many structures such as box culverts, hazardous waste containers, trench lines, floor drains, and in the repair and overlay of damaged cement concrete surfaces such as pavement and bridges.

In Iran, researchers Hassani, Gandjidoust and Maghanaki (4), investigated the possibility of using PET waste in asphalt concrete mixes as aggregate replacement (Plastiphalt) to reduce the environmental effects of PET disposal. This study focused on the parameters of Marshall Stability, flow, Marshall Quotient (stability-to-flow ratio) and density. Results showed indicated that the plastiphalt (the name of their product) material may be used cost effectively in pavements and as overlay on bridges.

Ismail and AL-Hashmi (5) investigated the efficiency of reusing waste plastic in the production of concrete. Thirty kilograms of waste plastic of fabriform shapes was used as a partial replacement for sand. This study showed that reusing waste plastic as a sand-substitution aggregate in concrete gives a good approach to reduce the cost of materials and solve some of the solid waste problems posed by plastics.

ESTIMATED PET CONSUMPTION

Since the aim of this project is to reduce discarded plastic (PET and HDPE) in the environment, it is essential to have a product that consumes an adequate volume of waste plastic. In preliminary trials, 10 concrete blocks (4”x 4”x 4”) consumed approximately 11 kg of plastic. A commercial size block has larger dimensions (16”x 4”x 8”) and will consume more plastic. To illustrate the volume of consumption, consider that a single storey dwelling with wall dimensions, 18’L x 26’W x 10’H, will require approximately 900 regular-sized blocks for just the exteriors walls. This correlates to more than 7920 kg of PET/HDPE per small dwelling that would otherwise go to a landfill.

Communities can benefit from reuse drives since they would be remunerated for returned PET bottles and hard plastic materials. Ultimately, this product will not only create a value added product (which is expected to have an overall cheaper operational cost than the regular concrete block), but also reduces environmental pollution and increases preservation of natural resources.

METHODOLOGY

1. Specimen Preparation and Testing

Laboratory specimens were made in accordance with the American Society for Testing and Materials (ASTM) Standard Method of Making and Curing Concrete Test Specimens in the Laboratory (C 192-90a). The unit weight of the specimens was measured in accordance with the ASTM Standard Test Method for Unit Weight of Structural Lightweight Concrete (C 567 – 85) and the Compressive Strengths of the Specimens were determined in accordance with the ASTM Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (C 39 – 86)

Prescribed portions of cement, sand and stone were weighed out in a metal pan and a prescribed amount of water was added (control specimens), note that the water content of the mix varied as cement content changed. The same process was followed for the cement, sand and plastic constituents (the PET and HDPE blocks were made separately). After mixing until a homogenous appearance was achieved, the samples were placed in 4 x 4 x 4 [inches] specimen molds and left to air dry for 24 hours at room temperature. After 24 hours, the specimens were removed from the molds and moist cured in a laboratory curing tank for, 7, 14 and 28 days. Upon completion of their cure time, the specimens were weighed and their failure loads read off.

2. Mix design

The variables, which compared the fundamental properties (density and compressive strength) of plastic blocks with the normal blocks, are listed in Table 1. These experimental variables indicate how the substitute aggregates affected the strength and weight of the blocks. The curing ages varied from 7, 14, and 28-days to consider the influence of cure time on the compressive strength. The cement and substitute aggregate contents were also varied to consider the optimal content for maximum strength.

RESULTS AND DISCUSSION

TABLE 1: Compressive Strengths of HDPE and PET Blocks to Normal Weight (standard Mixture) Blocks

AGE (DAYS)	NORMAL BLOCKS		HDPE BLOCKS		PET BLOCKS	
	Compressive strength Psi	Density kg/m^3	Mean Compressive strength Psi	Mean Density kg/m^3	Mean Compressive strength Psi	Mean Density kg/m^3
7	2031	5523.8	1312	4095.2	1000	2476.2
14	3293	5523.8	2781	4381.0	1197	2476.2
28	4843	5523.8	3781	4571.4	1250	2666.7

TABLE 2: Compressive Strengths of the HDPE and PET Blocks at different Plastic and Cement Content

Plastic content %	**Portland Cement Content** %	**HDPE BLOCKS** Compressive strength/ Psi	**PET BLOCKS** Compressive strength/ Psi
14	28	1312	1000
9	30	2781	1197
5	32	3781	1250

It should be noted that Strength requirements vary depending upon particular use. Structural lightweight concrete has compressive strength >2500psi), while low density and moderate strength concrete can have compressive strengths of 100-1000 psi and 1000-2500 respectively (Kosmatka/PCA).The plastic-aggregate blocks produced, physically resemble normal mixture blocks, with the exception of a marbled appearance where the plastic shows at the block surface; this may even be a desirable effect.

Generally, table 1 shows that while the plastic aggregate blocks have average lower compressive strengths they are lighter than the normal aggregate blocks. This is due to the relatively higher density of stones (2.3 – 2.4) to that of plastic, (0.94 – 0.97) which causes the blocks to be harder hence stronger. Further, stones have rougher surfaces than the plastic aggregates; this is conducive to good mechanical interlocking between the aggregate surface and the surrounding cement paste as a result of a stronger chemical bond formation between the molecules at the surface of the aggregate and the cement paste. In addition, the water absorption capacity of stone (1%) is greater than that of plastic (0%). This factor also contributed to the higher strength in the control specimens. Although there is an average lower compressive strength for the plastic specimen, the values are not significantly different. An analysis of variance–the ANOVA single factor method used to determine if there's a statistically significant difference between the control and the variables- showed that the mean compressive strength values for the control blocks and the plastic aggregate blocks were comparable. The values also indicated that the blocks can be used for structural lightweight concrete applications and for “low-density” and “moderate strength” lightweight concrete applications.

Table1.simultaneously shows a gradual increase in compressive strengths as the cure age increased. The continuous supply of water over a longer period facilitated an increase in the formation of calcium silicate hydrate bonds and calcium hydroxide crystals thus an increase in hardness, and consequently strength. One would also notice in Table 1 that desired strengths greater than 1500 psi are obtainable with later age of the plastic aggregate specimens i.e. 14 days and later.

Based on observations from Table 2, as cement content increases gradually, compressive strength also increases with respect to the plastic specimens. Simultaneously, we also see an increase in compressive strength as the plastic content decreases gradually. Although this is so, strengths obtained for the blocks with the highest plastic content and the lowest cement content still showed comparable compressive strengths to the normal aggregate blocks. Bond formation between the plastic aggregates and the cement paste is initiated by chemisorption (adsorption in which a single layer of molecules is held with great strength to a surface by a chemical bond). In this case the cement paste is held to the surface of the plastic aggregates. Results in Table 2 also showed higher compressive strengths for the blocks containing HDPE particles than those containing PET particles. This may have been due to the different nature of the aggregates. HDPE has a higher density than PET, this causes it to be harder hence stronger and consequently this characteristic results in a stronger block.

CONCLUSIONS

This study indicates that shredded PET and HDPE are viable aggregates for the production of a lightweight construction material. Results obtained indicated that the plastic aggregate blocks produced, were lighter than the normal aggregate concrete; there was an overall 22% reduction in weight. Statistical results performed showed that compressive strengths obtained for the plastic blocks were comparable with those obtained for the normal weight blocks hence can be used for most of the structural applications the normal aggregate blocks are used for.

Lessons Learned

Age, cement and plastic contents, appeared to be factors that influenced compressive strength of the plastic aggregate blocks. The nature (surface texture, density) of the plastic particles and their sizes may have influenced the chemisorption action and as a result the strength of the blocks. The smaller the plastic aggregates, the greater the surface area available for bond formation resulting in increased chemisorption activity and subsequently an increase in strength.

Expected Outcomes

- Creation of a value-added product (lightweight concrete blocks) and a saleable by-product (builder's waste substitute)
- Reduction in the amount of plastic waste present in the environment and a reduction in PET and HDPE waste entering landfill sites (anything that fills a landfill slower is a good thing)
- Creation of jobs (collection of PET and HDPE materials).

Expected Advantages

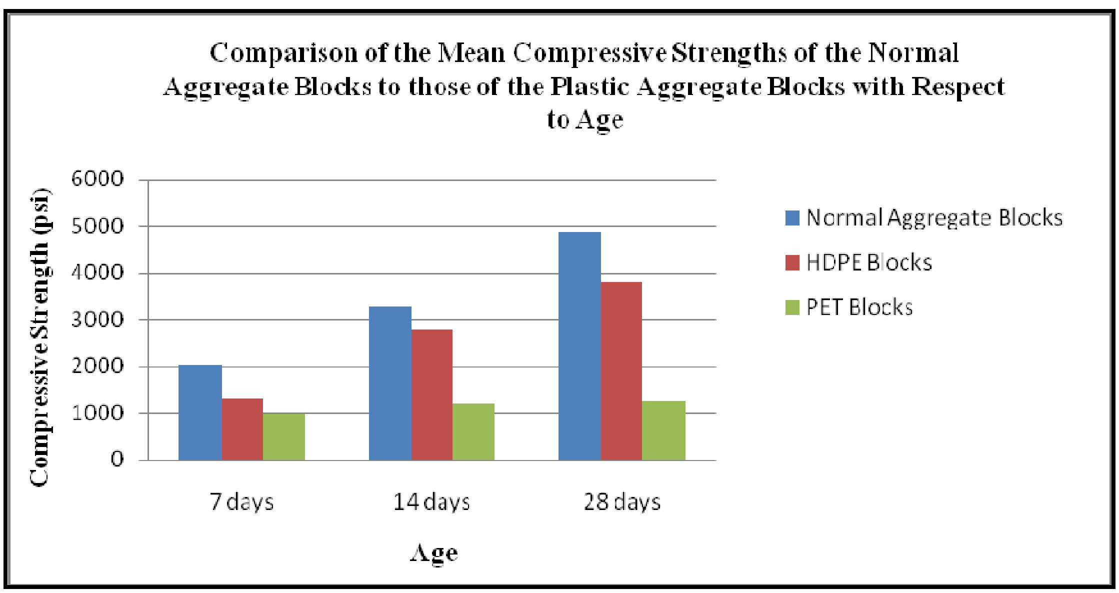
The market strength of this product is that it is able to consume a large amount of low cost waste material. Further, the market will always be present as housing is a continuous need. Due to its composition, this product may have certain advantages over the normal-aggregate blocks but more research needs to be done to verify these:

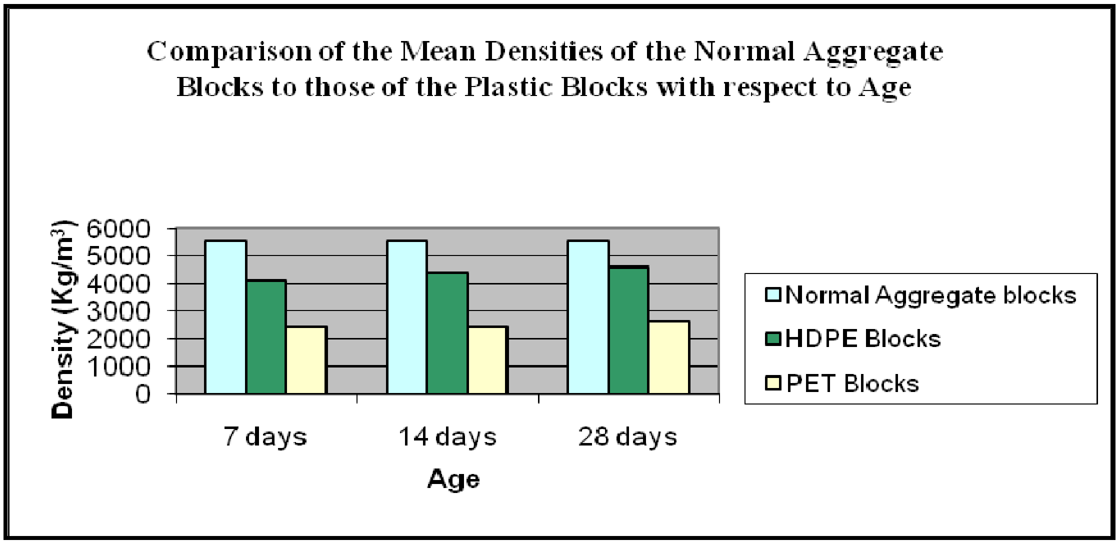
a. Greater resistance to weathering due to chemically inert PET and HDPE;
b. Less stress on foundation (due to lighter blocks);
c. Cheaper foundation (since the stress on foundation is less; the mixture will not need large amounts of stone and gravel);
d. Less manual stress in making blocks (mixture is lighter);
e. Less cost of transportation (due to lighter blocks);
f. Good sound insulation;
g. Variable strengths (dependent on size and nature of plastic aggregate);
h. Better shock absorption; and
i. Reduction in the dead load of concrete structure which allows the contractor to reduce the size of columns, footings and other load bearing elements

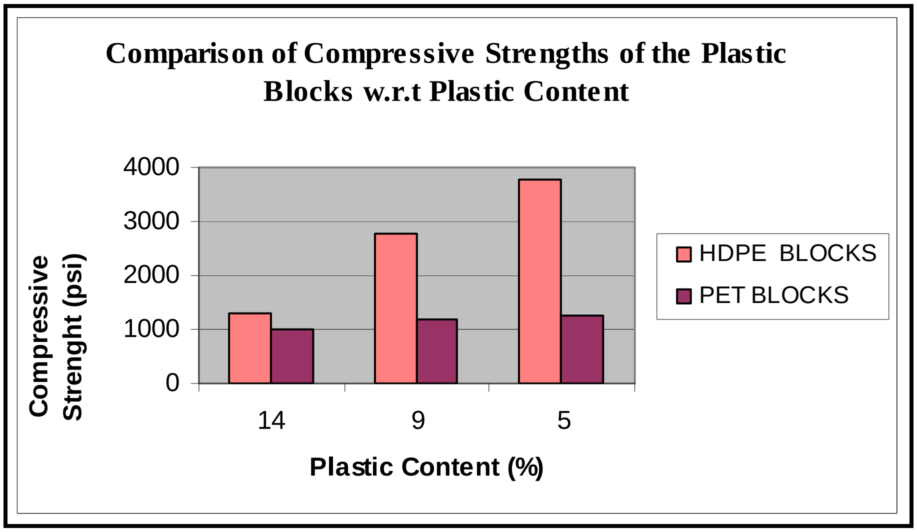
Future Work

Based on benchmark properties (compressive strength and unit weight) determined in this study, mix designs could be altered to achieve increased compressive strength. A decrease in the plastic aggregates size and the use of admixtures, among other alterations should be evaluated for increasing strength. In addition a detailed cost analysis should be done to determine the cost effectiveness of producing and operating with the plastic aggregate blocks. With the availability of specific instruments, further mechanical tests and a microscopic analysis should be carried out to better identify and understand the properties of the plastic blocks.

CHARTS and PICTURES




Comparison of the Mean Densities of the Normal Aggregate Blocks to those of the Plastic Blocks with respect to Age
Density (Kg/m³)
6000
5000
4000
3000
2000
1000
0
7 days
14 days
28 days
Age
Normal Aggregate blocks
HDPE Blocks
PET Blocks


Comparison of Compressive Strengths of the Plastic Blocks w.r.t Plastic Content
Compressive Strenght (psi)
4000
3000
2000
1000
0
14
9
5
Plastic Content (%)
HDPE BLOCKS
PET BLOCKS

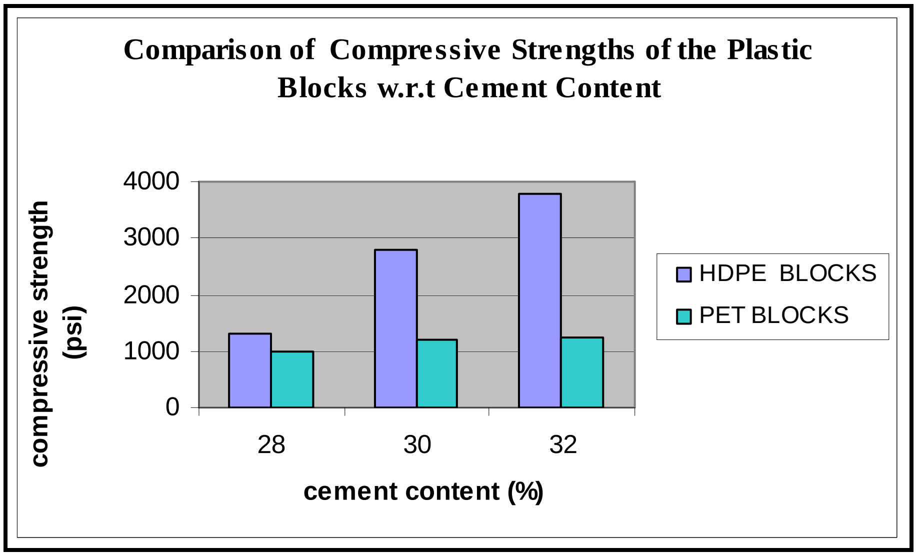

Comparison of Compressive Strengths of the Plastic Blocks w.r.t Cement Content
compressive strength (psi)
4000
3000
2000
1000
0
28
30
32
cement content (%)
HDPE BLOCKS
PET BLOCKS

Fig 1: HDPE block.

Fig 2: PET block.

Fig 3: Cross section through PET block after Compression Test.

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