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Flexural Properties of Finely Granulated Plastic Waste as a Partial Replacement of Fine Aggregate in Concrete

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Compressive strength

Abstract

The research work evaluates the structural properties of concrete with fine aggregates being substituted with granulated plastic waste [GPW] using high density polyethylene (HDPE). The plastic wastes were shredded and grounded into fine material passing through 0.5mm sieve. The fine aggregate was substituted from 0% to 50% (with 0% serving as the control) and water-cement ratio ranges from 0.6 for 0%-30% substitution and 0.7 for 40% and 50% using a concrete matrix 1:2:4. Various tests were carried out, workability, compacting factor and V.B consistometer on the wet concrete and compressive strength test on the hardened concrete after curing. Results showed that a wide range of high early strength was achieved with compressive strength of 21.42N/mm2, 17N/mm2 and 9.67N/mm2 for 10%, 20% and 30% fine aggregate replacement respectively while the control is 21.75N/mm2 at 28days test. It is recommended that a 10% replacement be used for structural works while 20% and 30% be used for non-structural works like solid ground floors and light weight concrete.

1. Introduction

The use of by-products in concrete has been a burning research over the last five decades. Efforts has been made to use industry by-products such as fly-ash, silica fume, ground granulated blast furnace slag (GGBS), glass cullet, palm kernel shell, etc in Civil Engineering constructions. The potential application of these by-products in concrete are as partial aggregate or cement replacement, depending on their grain size and chemical composition. Attention is focused worldwide on preserving and safeguarding the environment but re-using of waste (by-product) from our industries and human daily activities.

The addition of these by-products, apart from the environmental benefits, also has effect on the quality of the final product. One of the by-products, particularly used in concrete is recycled plastic. Plastic has been part of our daily life, ranging from pet bottles to wraps to shopping bags etc and thus generate into waste. Solving the disposal of this large volume of plastic material leads to re-use as an aggregate in concrete works. The re-use of plastic waste is presently uneconomical, but the gains to the environment are unquantifiable. The growth in the world plastic industry has been enormous, from a little over three million tonnes in 1955 to thirty million tonnes in 1977 [1]. The menace caused by the disposal (or dispersal) of plastic waste in developing country like Nigeria unimaginable.

The effect of polypropylene fibres on the air content of concrete was studied and reported that air content increased at significantly at 0.3% inclusion [2]. In the study of the tensile strength of a 35MPa Portland cement concrete by substituting the aggregates with rubber particle. It was found that a reduction of up to 50% in tensile strength was gotten when the coarse aggregate was replaced by rubber [3]. In 1997, the effect of plastic aggregated on splitting tensile strength of concrete with the split tensile strength measured at different water-to-binder ratio was investigated and the conclusion was that the splitting tensile strength decrease with an increase in plastic aggregate replacement [4].

It was reported that the incorporation of rubber shreds (two different shapes of rubber particles as constituents of mortar) help in reducing plastic shrinkage cracking in comparison to control specimen [5]. In an investigation on workability of rubcrete in 1999, the report shows a decrease in slump with increase in rubber contents as a percentage of total aggregate volume, noting that a rubber content of 40% produces zero slump, making concrete not workable [6]. In another work on freeze-thaw durability of concrete rubber composites through the use of the two types of rubber aggregates, the compact rubber aggregate (CRA) and expanded rubber aggregate (ERA) with volume ranging from 9% to 40% [7]. The results show that there were improvement at 30% and 40% with ERA performing better than CRA observing that ERA mixes showed better flow and no segregation [8][9].

In separate investigation on the effect of replacing fine aggregate with grounded plastic on the slump of concrete, with 20% replacement, a decrease of 25% of the original slump was recorded [10][11]. Also in 2007, a study of the model use of granulated plastic pet bottles waste as substitution for fine aggregate was undertaken. The pet bottles were shredded and grinded into particles passing through sieve mesh up to 10mm and were used to replace sand between 2% to 100%. It was discovered that substituting sand at a level below 50% by volume whose upper granular limit equals 5mm, gives appreciable strength values that is good for light weight concrete [12].

It was all concluded in different researches that the continuous addition of granulated plastic into concrete matrix will cause a reduction in the strength. For a 20% replacement, the compressive strength shows a sharp reduction up to 72% of the strength of the control specimen [13][10][12].

2. Methodology

The plastic waste were collected from open sources, cleaned, extruded, cut into pieces and crushed into fine aggregate for the purpose of this research work. The grinded plastic materials pass through the 4.75mm sieve. Also too, sieve analyses were performed on the fine and coarse aggregates. 200g of each sample was weighed and allowed to pass through standard set of sieve. The retained aggregate on each sieve was weighed. The percentage passing was calculated and plotted against the sieve size.

The weight batching method was employed in the mix proportioning. The quantity of materials required was calculated using mix ratio [1:2:4]. Having obtained various mix portions, a water cement ratio of 0.6 was used for up to 30% replacement while for 40% and 50%, a water/cement ratio of 0.7 for good workability of concrete. These were determined by the slump test which was carried out according to British Standard [14]. This clearly shows that increases in the replacement of fine aggregate with granulated plastic waste will lead to an increase in the amount of water required for a workable concrete. The following tests on workability were carried out: the slump test, compaction factor test and V.B Constitometer test. The mixed concrete was then placed in the 150mm cube mould and compacted.
The cube samples were de-moulded after 24hours and cured in the curing tank for a period of 7, 14 and 28 days. At the end of each period, the samples were tested for deflection using the compression testing machine.

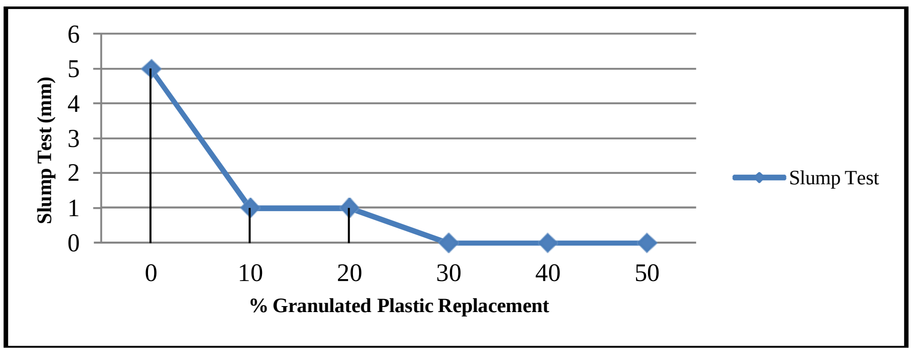
3. Results

3.1 Workability Tests

The workability tests and corresponding water-cement ratio for each mix is shown below:

Table 1. Slump Test

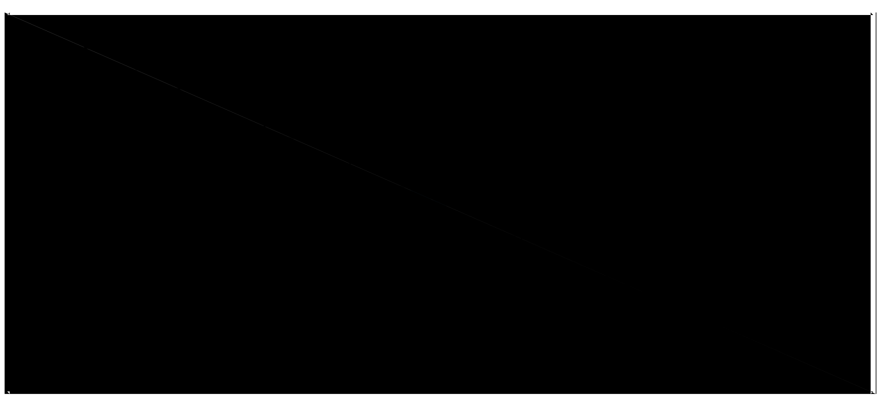
Mix Proportion	% Granulated Plastic Replacement	Water-Cement Ratio	Result (mm)
1:2:4	0	0.6	5
1:[0.2:1.8]:4	10	0.6	1
1:[0.4:1.6]:4	20	0.6	1
1:[0.6:1.4]:4	30	0.6	0
1:[0.8:1.2]:4	40	0.7	0
1:[1:1]:4	50	0.7	0



Graph 1. Graph of % GPR and Slump Test

Table 2. Compacting Factor Test

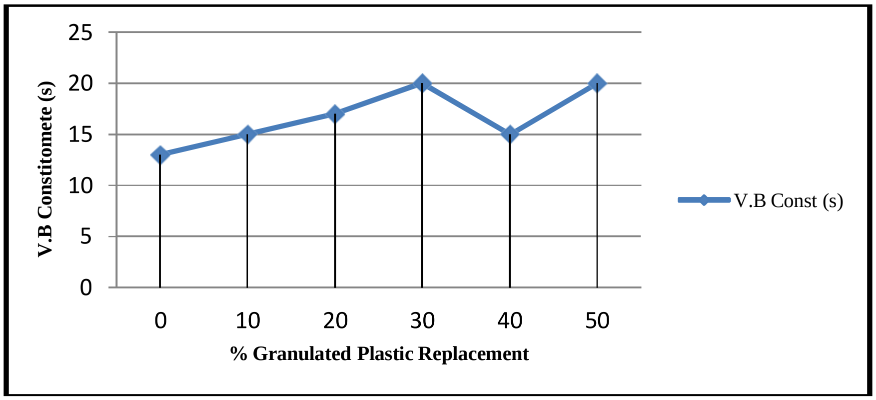
Mix Proportion	% Granulated Plastic Replacement	Water-Cement Ratio	Result
1:2:4	0	0.6	0.86
1:[0.2:1.8]:4	10	0.6	0.83
1:[0.4:1.6]:4	20	0.6	0.80
1:[0.6:1.4]:4	30	0.6	0.73
1:[0.8:1.2]:4	40	0.7	0.76
1:[1:1]:4	50	0.7	0.75



Graph 2. Graph of % GPR and Compaction Factor Test

Table 3. V.B. Constitometer Test

Mix Proportion	% Granulated Plastic Replacement	Water-Cement Ratio	Result (s)
1:2:4	0	0.6	13
1:[0.2:1.8]:4	10	0.6	15
1:[0.4:1.6]:4	20	0.6	17
1:[0.6:1.4]:4	30	0.6	20
1:[0.8:1.2]:4	40	0.7	15
1:[1:1]:4	50	0.7	20



Graph 3. Graph of % GPR and V.B Constitometer Test

From the laboratory workability test table in Table 1 - 3, it shows that as the percentage of granulated plastic waste increases, the slump and compacting factor tests values decreases while V.B Constitometer test values increases which made the concrete workability to reduce.

3.2 Compressive Strength (N/mm^2)

Compressive strength after 7, 14 and 28 days are given in the below table:

Table 3. Compressive Strength (N/mm^2)

% Replacement of fine aggregate with GPW	Compressive Strength (N/mm^2)		
	7 days	14 days	28 days
0	16.91	18.67	21.75
10	18.25	19.00	21.42
20	15.25	15.23	17.00
30	7.08	9.42	9.67
40	4.50	4.92	6.17
50	2.83	3.83	3.25

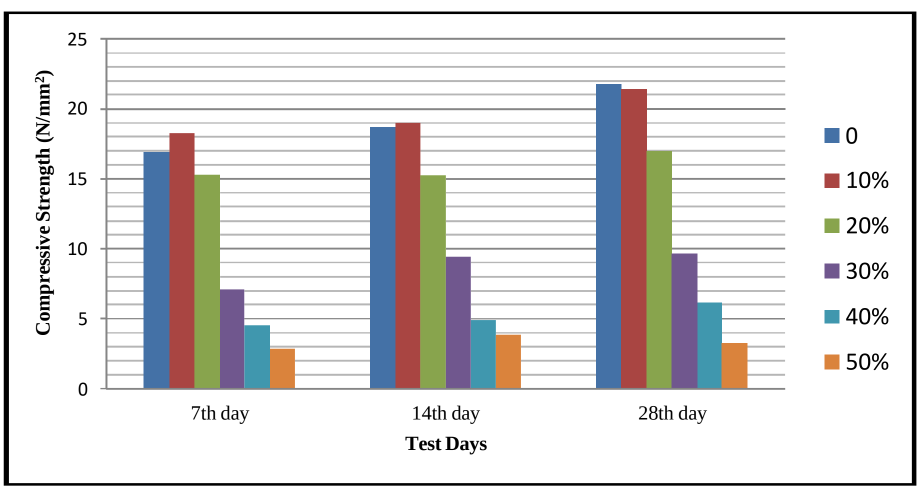
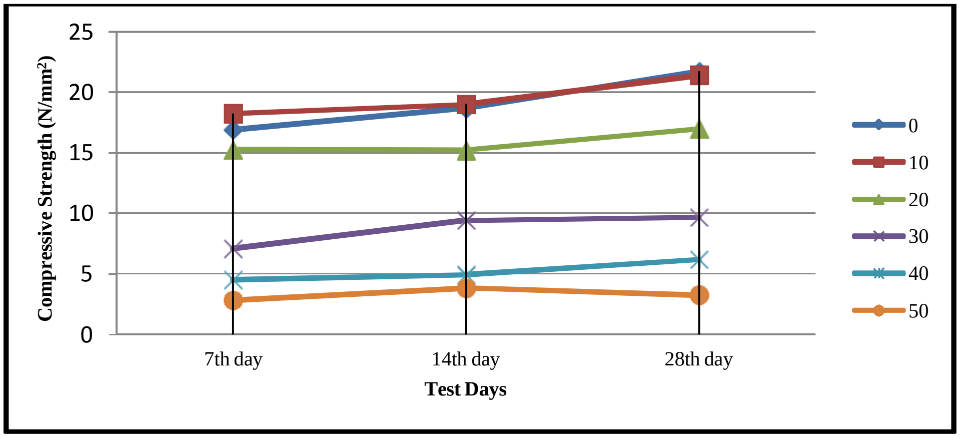


Figure 1. Compressive Strength at 7, 14 and 28 days



Graph 4. Compressive Strength at 7, 14 and 28 days

At noticed, the control and 10% replacement provided the same flexural properties and have about the same strength across 7, 14 and 28 days, while 20% has appreciable strength and above that has a reduction in strength from 56% to 85%.

4. Conclusion

The workability reduced as the amount GPW increased thus the addition of GPW requires more water for improve workability. However addition of more than 10 % GPW did not lead to any improved properties. This research clearly shows that increases in the replacement of fine aggregate with GPW will lead to an increase in the amount of water required for a workable concrete.

The 10% replacement mix was able to attain comparable strengths as that of the control mix. Hence replacing of fine aggregate by 10 % granulated plastic waste by volume is recommended for attaining concrete with improved properties as ordinary concrete. With good quality control mechanism, the 20% and 30% can also be used depending on the nature of work and structural requirement of the structure.

The usage of plastic waste has other benefit. It can reduce the environmental pollution caused by indiscriminate disposal of plastic waste. Moreover it can also be used in the construction of low cost structures where light weight concrete are required.

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