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The Evaluation of Mechanical Properties in Concrete using Polyethylene as Admixture

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Abstract

This study examined the effect on some concrete's mechanical properties using polyethylene (PE) as admixture. These have become imperative due to the environmental pollution these waste plastics constitute in our society. The experimental research design was used in this work. The pulverization of the PE was done in order for it to blend with the concrete. The percentages of the pulverized PE in the concrete were 5 %, 10 %, and 15 % by weight of sand. The preparations of various types of concrete specimens were carried out. The concrete specimens were tested for flexural and compressive strength at a curing period of 3 days, 7 days, 14 days, and 28 days respectively. Results obtained show a reduction in the compressive and flexural strength at 5 % and 10 % by weight of the PE concrete at 28 days of curing duration. However, there was a gradual increase in compressive and flexural strength at 15 % by weight of PE concrete at 28 days of curing period but below the control's concrete by 8.2 % and 11.1 % in compressive and flexural strength respectively. Therefore, polyethylene has a prospect of being used in concrete, especially in the construction industry.

1. Introduction

The enormous deposit of waste polymer materials seen globally is due to rapid urbanization and industrialization. The global annual consumption of plastic materials has increased from 5 million tonnes in the 1950s to nearly 381 million tonnes in 2015 [1]. Polyethylene (PE) is a waste plastic bag which is a non-degradable material which gives high impact pollution to the environment. Channeling such wastes to other constructive purposes is quite desirable [2]. Waste polymer materials consist of surplus, obsolete, broken, old plastic furniture, different household plastic materials, equipment, anti-static packaging materials and devices made of plastic. These polymer wastes are usually non-decomposable in the habitat even after a prolong period of exposure [3]. A research study by Mahesh et al. [4] evaluated the use of waste polyethylene as partial substitution of sand or granite in concrete. Concrete containing 2 %, 4 %, 6 % pulverized/non pulverized polyethylene material was prepared. Mix designs of M25 grade concrete with and without plastics were carried out. It was concluded that waste plastic could be effectively re-used without affecting the mechanical properties considerably; within a (5-10) % margin. A sudden reduction in early strength was noted with increase in the percentage of plastic, but the strength developed to the control value as at 28 days of curing period.

Raju [5] presented the results of their experimental study on the use of polyethylene hand cut macro fiber on the mechanical properties of cement concrete. The polyethylene in fiber form with sizes of 120 mm length and 4 mm width were used to replace the fine aggregate. The fine aggregate was replaced by plastic fiber with 1 % by weight. The observation was that the compressive strength of cement concrete reduced after the inclusion of plastic fiber. The inclusions of plastic fiber had no significant effect on tensile strength. It was seen that there was chemical reaction of plastic fiber with the matrix during the hydration process. This was due to the density difference in fine aggregate and polyethylene. The compressive strength significantly decreased by 50.42 % at 28 days. The tensile strength decreased by 8.52 % which is nominal as compare to the compressive strength decrement rate.

Nabajyoti and Brito [6] in their paper reported on the evaluation of the strength characteristics of concrete containing various types of recycled polyethylene terephthalate (PET) aggregate. The result obtained show that the compressive strength development of concrete containing all types of PET-aggregate behaved like the control's concrete, but the PET-aggregate significantly lowered the compressive strength of the blended concrete. The incorporation of the PET-aggregate improved toughness behavior of the resulting concrete specimen. This behavior that was observed depended on the PET-aggregate's shape and was maximized for concrete containing coarse, flaky PET-aggregate. The compressive strength of concrete containing plastic aggregates was proportional to the splitting tensile and flexural strength characteristics.

Raghatate [7] has also carried out research on use of plastic in concrete to better its properties. The properties of concrete containing varying percentages of plastic were tested for compressive strength and split tensile strength and shows that an appreciable increase in tensile strength of concrete can be achieved by introducing cut pieces of plastic bags. He concluded based on the experimental result and the following points are summarized with regard to effect of plastic on the properties of concrete.

The compressive strength of concrete is affected by the addition of plastic pieces and it goes on decreasing as the percentage of plastic increases. Raghatate [7] reported further that the addition of 1 % of plastic as partial replacement in concrete causes about 20 % reduction in strength after 28 days curing. The splitting tensile strength observation shows the improvement of tensile strength of concrete. Up to 0.8 % of plastic improvement of strength was recorded after that addition of strength of concrete decreases with addition of plastic thus, it was concluded that the use of plastic can be possible to increase the tensile strength of concrete if not its compressive strength.

It can be seen that literatures are filled with researches on partial replacements of polyethylene in concrete but little or no attention have been given to the pulverized polyethylene being used as admixture in concrete. This research tends to investigate some mechanical properties of concrete when pulverized polyethylene is used as an admixture.

2. Methodology

The materials used consist of pulverized polyethylene (PE) sample as shown in Figure 1, Portland cement, crushed coarse aggregate of 20 mm size, water and fine aggregate. The tools used included beam moulds (100 mm x100 mm x 500 mm) size, steel mould of (100 mm x100 mm x 100 mm) size, shovel, head pans and concrete mixer. University of Benin (UNIBEN) sachet water bags (polyethylene) were obtained.

Figure 1: Pulverized polyethylene (PE) sample

The pulverization of the polyethylene (PE) was carried out prior to its addition to concrete at weighted percentages of 5 %, 10 %, and 15 % of the fine aggregate as admixture. The PE concrete specimen produced according to BS 1881: Part 108 [8] methodology were seventy-five (75) moulds of dimensions 100 mm x 100 mm x 100 mm and fifty (50) beam of dimensions 100 mm x 100 mm x 500 mm. After the curing duration of 3 days, 7 days, 14 days, and 28 days on the concrete specimens, compressive and flexural tests were carried out. Flexural and compressive strength tests were conducted according to BS EN [9] and BS EN [10] respectively. Several other tests were also carried out on the material.

Design-Expert 7.0 software was used to carry out the design for the polyethylene concrete as shown in Table 2. The values of 5 %, 10 % and 15 % respectively by weight of the pulverized polyethylene, corresponding to the 3 days, 7 days, 14 days and 28 days of the curing durations were used to produce the polyethylene concrete. The compressive and flexural strengths of the PE concrete were obtained as stated in Table 3. The F-test was used to check the significance of the model while adequacy of the model was done by the coefficient of determination (R^2).

3. Results and discussion

3.1 Sieve analysis test

The sand and the pulverized polyethylene (PE) were subjected to sieve analysis test according to [11]. The results are shown in Figure 1 and Figure 2 respectively.

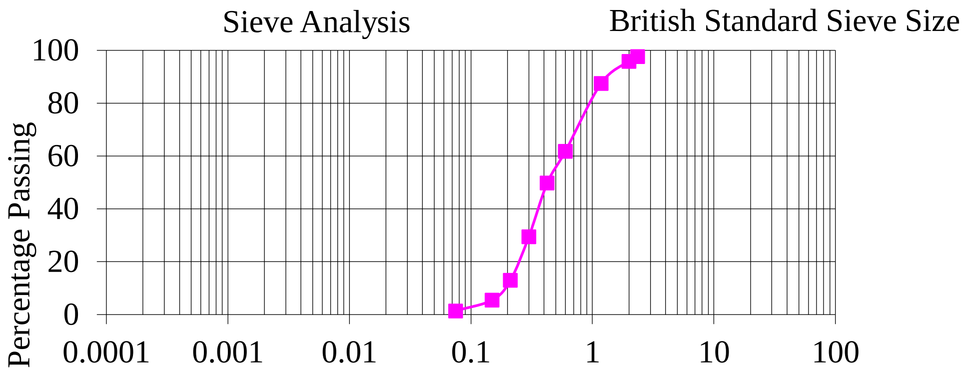

Figure 2: Sieve analysis for the fine aggregate

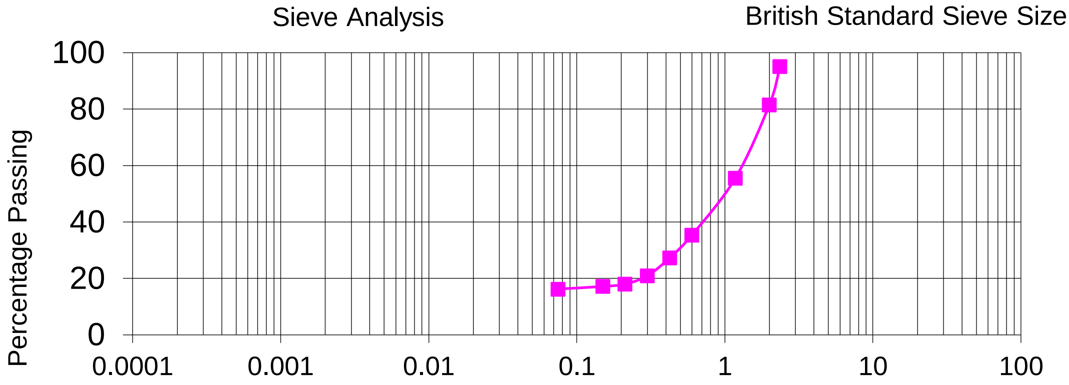

Figure 3: Sieve analysis for the polyethylene (PE) sample

3.2. Specific gravity test

The samples of the fine aggregate and the pulverized PE were subjected to specific gravity test based on ASTM C127 [12] methodology. The results showed that the fine aggregate has 2.54 while that of pulverized PE was 0.68. This depicts that the fine aggregate is heavier in weight than the pulverized PE.

3.3. Slump Test

The slump test results for the concrete containing 0 %, 5 %, 10 %, and 15 %, of PE content by weight are presented in Table 1.

Table 1: Pulverized PE and control concrete slump test.

Pulverized PE (%)	Slump (mm)
0	38
5	6
10	5
15	<5

Slump test results for the blended concrete of 0 %, 5 %, 10 %, and 15% by weight of the PE content were shown in Table 1. A decrease in workability was observed as PE content increased in the concrete. The low workability may be due to the increase in surface area of the blended concrete because of the presence of plastic in the mix thereby making the slump dry. This was collaborated by [13].

3.4 Flexural and compressive strength test

The experimental design and responses of the concrete using the several percentages of PE are contained in Table 2 and Table 3. The compressive strength of the PE concrete showed a reduction when compared to the control's concrete compressive strength at 28 days of curing. At 28 days of curing duration the control concrete compressive strength was 37.7 N/mm^2. While the compressive strength of the PE concrete at 28 days of curing for 5 %, 10 % and 15 % additive were 31.3 N/mm^2, 30.3 N/mm^2 and 34.6 N/mm^2 respectively. These show an improved result of the 15 % by weight of PE concrete's compressive strength than that of the 10 % by weight of PE concrete and 5 % by weight of PE concrete's compressive strengths at 28 days curing duration, as shown in Table 3 and Figure 4. These may be due to the PE acting as reinforcement in the concrete at higher quantities. This was collaborated by [14] and [15]. However, the control's concrete compressive strength was higher than the compressive strength of the 15 % by weight of the PE concrete by 8.2 %. Likewise for the flexural strength there was a decrease in strength. The control's concrete and PE concrete flexural strengths at 28 days of curing for 0 %, 5%, 10 % and 15 % by weight are 3.6 N/mm^2, 2.7 N/mm^2, 2.4 N/mm^2 and 3.2 N/mm^2 respectively. The 15 % by weight of PE concrete has shown improved results than the 10 % by weight of PE concrete and 5 % by weight of PE concrete at curing period of 28 days, as shown in Table 4 and Figure 5. These may be due to the PE acting as fibre reinforcement in the concrete at higher quantities. This was collaborated by [7]. However, the control's concrete flexural strength was higher than the flexural strength of the 15% by weight of the PE concrete by 11.1 %.

The coefficient of determination (R^2) of 0.9442 was obtained in the model. This is a pointer that 94.42% of the variations in the compressive strength of the concrete were explained by the independent variables. The F-test value of 12.09 and the p-value of 0.0002 have shown that the quadratic model is significant. Similarly, the result of the quadratic model for the flexural strength of the PE concrete gives the R^2 of 0.9166. It indicates that 91.66 % of the variations in the flexural strength of the PE concrete were explained also by the independent variables. The significance of the model of PE concrete's flexural strength was explained by the F-test value of 7.85 and the p-value of 0.012 respectively.

Table 2: Experimental design value for the PE concrete

STD	RUN	FINE AGGREGATE (KG)	COARSE AGGREGATE (KG)	% OF POLYETHYLENE (KG)	CURING DURATION (DAYS)	W/C RATIO (KG)	CEMENT (KG)
23	1	9.875	18.330	10	3	3.276	6.427
24	2	9.298	18.330	15	3	3.276	6.427
12	3	9.554	18.330	15	28	3.276	6.427
20	4	9.298	17.657	0	14	3.276	6.427
14	5	9.875	17.900	15	14	3.276	6.427
7	6	9.875	17.552	0	3	3.276	6.427
19	7	9.298	18.330	10	14	3.276	6.427
15	8	9.875	17.254	5	14	3.276	6.427
3	9	9.298	17.254	0	3	3.276	6.427
10	10	9.875	18.330	10	3	3.276	6.427
1	11	9.875	17.254	15	28	3.276	6.427
13	12	9.298	18.330	0	28	3.276	6.427
21	13	9.565	18.330	0	7	3.276	6.427
16	14	9.569	17.789	5	28	3.276	6.427
18	15	9.298	17.287	15	7	3.276	6.427
2	16	9.298	18.330	15	3	3.276	6.427
22	17	9.875	17.552	0	3	3.276	6.427
8	18	9.383	17.804	5	3	3.276	6.427
11	19	9.553	17.254	0	28	3.276	6.427
9	20	9.565	18.330	10	7	3.276	6.427
6	21	9.643	17.254	5	3	3.276	6.427
4	22	9.298	17.254	15	28	3.276	6.427
25	23	9.298	17.254	0	3	3.276	6.427
17	24	9.875	18.242	10	28	3.276	6.427
5	25	9.875	18.330	0	28	3.276	6.427

Table 3: Experimental design and responses for the PE concrete

STD	RUN	FINE AGGREGATE (KG)	COARSE AGGREGATE (KG)	% OF POLYETHYLENE (KG)	CURING DURATION (DAYS)	W/C RATIO (KG)	CEMENT (KG)	COMPRESIVE STENGTH (N/mm^2)	FLEXURAL STRENGTH (N/mm^2)
23	1	9.875	18.330	10	3	3.276	6.427	20.7	2.10
24	2	9.298	18.330	15	3	3.276	6.427	23.7	2.25
12	3	9.554	18.330	15	28	3.276	6.427	32.0	3.15
20	4	9.298	17.657	0	14	3.276	6.427	29.0	3.00
14	5	9.875	17.900	15	14	3.276	6.427	30.5	2.40
7	6	9.875	17.552	0	3	3.276	6.427	26.7	2.85
19	7	9.298	18.330	10	14	3.276	6.427	29.2	2.33
15	8	9.875	17.254	5	14	3.276	6.427	28.2	2.25
3	9	9.298	17.254	0	3	3.276	6.427	23.0	2.40
10	10	9.875	18.330	10	3	3.276	6.427	19.5	2.25
1	11	9.875	17.254	15	28	3.276	6.427	34.6	3.20
13	12	9.298	18.330	0	28	3.276	6.427	31.0	3.60
21	13	9.565	18.330	0	7	3.276	6.427	29.7	3.10
16	14	9.569	17.789	5	28	3.276	6.427	31.3	2.70
18	15	9.298	17.287	15	7	3.276	6.427	28.7	2.25
2	16	9.298	18.330	15	3	3.276	6.427	28.3	2.40
22	17	9.875	17.552	0	3	3.276	6.427	28.3	2.40
8	18	9.383	17.804	5	3	3.276	6.427	19.3	2.10
11	19	9.553	17.254	0	28	3.276	6.427	33.7	3.60
9	20	9.565	18.330	10	7	3.276	6.427	25.3	3.00
6	21	9.643	17.254	5	3	3.276	6.427	21.3	2.40
4	22	9.298	17.254	15	28	3.276	6.427	33.3	3.10
25	23	9.298	17.254	0	3	3.276	6.427	23.0	2.25
17	24	9.875	18.242	10	28	3.276	6.427	30.3	2.40
5	25	9.875	18.330	0	28	3.276	6.427	37.7	3.90

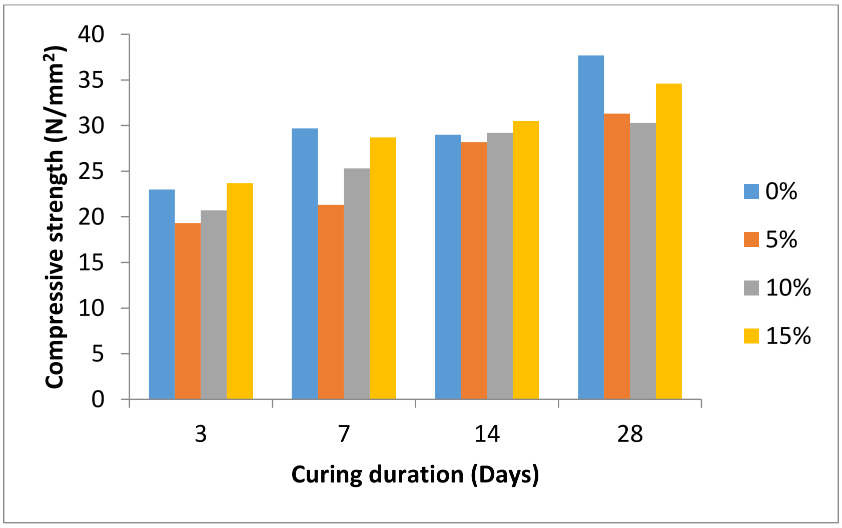

Figure 4: Compressive strength and percentages of PE additive graph

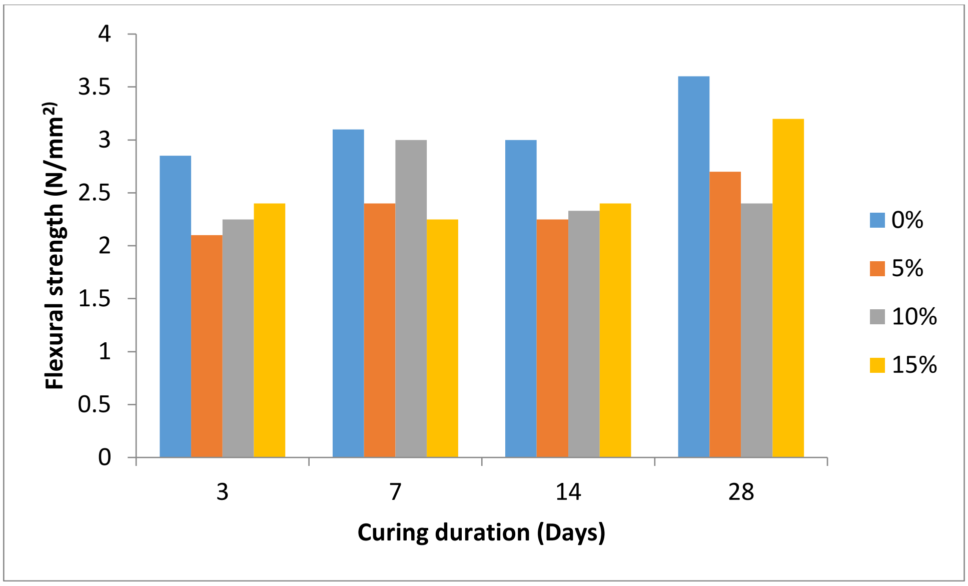

Figure 5: Flexural strength and percentages of PE additive graph

3.5. Discussion

The aftermath of PE on the compressive strength of the blended concrete

The three-dimensional plot of percentages of polyethylene (PE) and period of curing on the compressive strength of the blended concrete are shown in Figure 5. There was an initial decrease in compressive strength as the addition of polyethylene percentage increased. The decrease was observed up to 10 % by weight addition of the pulverized polyethylene at 28 days of curing period. This may suggest that the pulverized polyethylene may not have proper bonding with cement. This was collaborated by [14]. At 15 % by weight of PE, the compressive strength was increasing when cured for 28 days period.

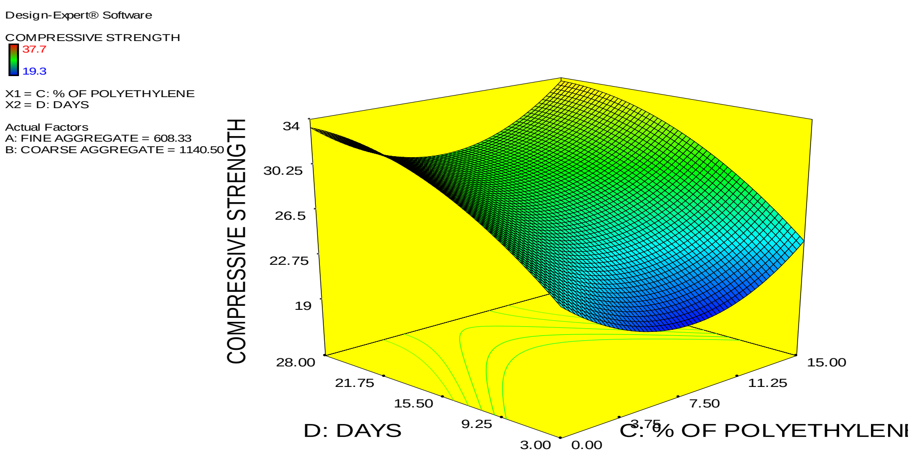

Figure 6: Compressive strength and percentages of PE additive 3D graph

3.6. The aftermath of PE on the flexural strength of the blended concrete

The three-dimensional plot of percentages of polyethylene (PE) and period of curing on the flexural strength of the blended concrete are shown in Figure 6. There was a progressive decrease in flexural up to 10 % by weight of polyethylene addition at 28 days curing duration. At 15 % by weight of polyethylene additive to the concrete, there was an appreciable increase of flexural strength at 28 days curing duration. This may be due to the PE acting as fibre reinforcement in the concrete which was collaborated by [13].

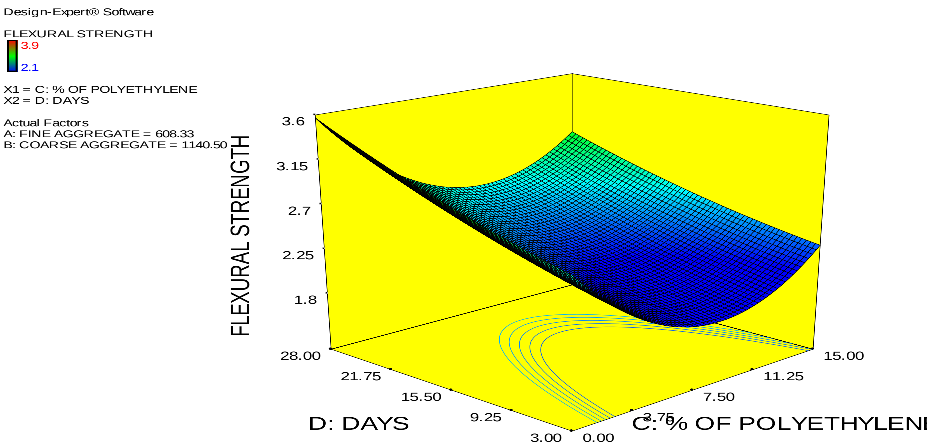

Figure 7: Flexural strength and percentages of PE additive 3D graph

4. Conclusion

It can be concluded from the study that, visible reduction in workability was noticed as the PE contents improved in the blended concrete. The compressive strength of the 15 % by weight of PE concrete was higher than the compressive strength at 5 % and 10 % by weight of PE concrete, at day 28 of curing but lower by 8.2 % when compared to the compressive strength of the control concrete. The flexural strength of the 15 % by weight of PE concrete was higher than the flexural strength for 5 % and 10 % by weight of PE concrete at day 28 of curing but lower by 11.1 % when compared to the flexural strength of the control concrete. Structural applications should be encouraged for the usage of 15 % by weight of PE concrete. There may be several advantages in using PE for concrete works which may include production of green sustainable concrete and helping in reducing environmental pollution.

Conflict of interest

The authors declare that they have no conflict of interest.

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