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Review article

The effect of using polyethylene terephthalate as an additive on the flexural and compressive strength of concrete

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ABSTRACT

The annual consumption of plastics in Nigeria has increased drastically and plastic wastes recycling has become one of the major challenges in recent times. Polyethylene Terephthalate (PET) has been selected in this study to ascertain its possible use as an additive in concrete construction. The study used the experimental research design in carrying out its work. The PET was pulverized so that it can mix with the concrete. The pulverized PET was used in concrete with percentages of 5 %, 10 %, and 15 % by weight of conventional fine aggregate. Four types of concrete specimens including the control were prepared. The flexural and compressive strength of the concrete specimens were tested, after a curing period of 3 days, 7 days, 14 days, and 28 days respectively. The result showed that the concrete specimen containing PET at 5 % by weight showed higher compressive strength than other specimens. The flexural strength of concrete specimens containing PET aggregate was below that of the control concrete.

1. Introduction

Concrete is made up of cement, fine aggregate, coarse aggregate, and water. They are used globally for the production of concrete (Kolhapure et al., 2018). Concrete estimated usages are up to 11 billion metric tons yearly because it is the most frequently used construction material globally (Praveen et al., 2013). Due to the usage of concrete, these aggregate resources are getting scares thus requiring an alternative with the passing of each day. The searches of local materials, which can be the best substitute for the concrete material, are matters of serious concern for civil engineers (Praveen et al., 2013). The continuity of the construction industry is very critical, hence seeking aggregates for concrete and other replacements of the conventional aggregates are paramount. The aggregate alternative used in this study is called polyethylene terephthalate (PET).

Polyethylene terephthalate (PET) also known as polypropene is a thermoplastic material used in various applications such as food wrapping, clothing, building materials, rope and constitutes a major fraction of household wastes. In recent years, shredded synthetic fibers such as polyethylene (Wang et al., 2016), polyvinyl alcohol (PVA) (Sahmaran and Yaman, 2007), polyethylene terephthalate (PET) (Foti, 2013) and polyethylene (PP) have been added to the concrete as reinforcements to enhance the mechanical and engineering properties of the concrete.

In a study carried out by Albano et al. (2009), they replaced sand in concrete with polyethylene terephthalate (PET) with two different w/c ratio (0.50 and 0.60). The PET specimen sizes are 0.26 (small) and 1.14 cm (big), respectively. The replacement of sand was done with 10 % and 20 % by volume of PET with particle sizes of 0.26 and 1.14 cm and a 50/50 mix of both sizes. Workability was determined with the help of a slump test. It was observed that there was a higher slump for the blends with 10 % of recycled PET, for determining particle size. A higher slump value was observed for the PET blend with a 50/50 particle size when compared to the blends with PET particles of 0.26 and 1.14 cm. PET affected the slump but it had more effect on slump when there was an increase in the w/c ratio (Albano et al. (2009).

Furthermore, Ramadevi and Manju (2012) used waste PET bottles in fiber form as the partial replacement of fine aggregate in 25Mpa grade of concrete specimens with 0.45 w/c ratio in various percentages 0.5 %, 1 %, 2 %, 4 %, and 6 %. Mix design of 25Mpa grade concrete was done following the guidelines of IS 456 (2000) and IS 10262 (2009). It was reported that a 2% replacement of the fine aggregate with PET bottle fibers gave an appreciable increase in the compressive strength. Beyond 2%, the compressive strength was found gradually reducing.

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However, Frigione (2010) used waste unwashed PET bottle (WPET) as a replacement of fine aggregate. 5% by weight of WPET was replaced by the fine aggregate in concrete. Compressive strength was determined at 28 days and 365 days. It was observed that at 28 days, the compressive strength slightly decreased (not lower than 2%) when WPET was added in substitution of natural sand in comparison to the reference concrete. The differences in compressive strength observed at 28 days were alike to those measured at 365 days. The compressive strength at 28 days and 365 days of WPET concrete was between 0.4 %–1.9 % lower than the control concretes.

More so, Choi et al. (2005) reported on the effects of waste PET bottles on properties of concrete. They observed that the weight of conventional concrete can be decreased by 2%–6 % of waste plastics, but there was a 33% reduction in the compressive strength to that of normal concrete.

Similarly, Islam et al. (2011) in his research used PET to replace coarse aggregates in concrete where he shredded, melted, and crushed the collected waste PET bottles. He found out that at 20 % PET replacement of PAC (PET aggregate concrete) at 0.42 w/c ratio; the compressive strength was 30.3 MPa, which was only 9% less than the NAC (Normal aggregate concrete). However, 1.8 cm slump value was observed for 20 % PET replaced PAC at 0.42 w/c ratio which has significantly high workability. It was concluded that PET replaced concrete with a low w/c ratio and high workability can be used for structural concrete applications.

Baboo et al. (2012) reported in their study that with varying percentages by volume of sand was partially replaced by waste plastic flakes in concrete. Waste plastic mix concrete with and without super-plasticizer. Compressive strength tests were carried out for forty-eight cube samples at 3 days, 7 days, and 28 days. The flexural strength characteristic of waste plastic mix concrete was studied using eight beams that were concreted. It was found out that due to partial replacement of sand by waste plastic, there was a minimal reduction in workability and compressive strength, and this can be enhanced by the addition of super-plasticizer.

Industrialization and the considerable improvement in the standards of living have increased quantities of waste plastic rapidly during recent decades. Bottles made from polyethylene terephthalate (PET) deposited in domestic wastes and landfills, which are not bio-degradable cause environmental issues in most regions. Serious problems such as environmental pollution may arise when these wastes are not recycled but rather abandoned (Ahmad, 2014). One of the efficient measure in the management of the waste materials are the recycling and reusing of these waste material, which also prevents pollution and conserves natural resources.

The usage of PET as a partial replacement in concrete is widely known according to literature but using the PET as an additive in concrete is not widely known. This work aims to study the effects of pulverized polyethylene terephthalate as an additive on the compressive and flexural strengths of concrete using specimens tested after 3 days, 7 days, 14 days and 28 days of curing.

2. Materials and method

Portland cement, 19 mm coarse aggregate, fine aggregate, polyethylene terephthalate (PET), and water were used as materials for the concrete. The polyethylene terephthalate was pulverized before it was added to grade 25 concrete at 5%, 10%, and 15% by weight as additive. Seventy-five (75) moulds of dimensions 100 mm × 100 mm x 100 mm and fifty (50) beam of dimensions 500 mm × 100 mm x 100 mm PET concrete specimen was produced according to BS 1881: Part 108 (1983) methodology. These concrete specimens were prepared at the Civil/Structural Engineering laboratory at the University of Benin, Benin City, Nigeria. Flexural and compressive tests were carried out on the specimens for 3 days, 7 days, 14 days, and 28 days curing interval. The third point flexural test method was used to obtain their various flexural strengths according to BS EN 12390–5:2009 methodology. The BS EN 12390–3:2019 methodology was used for the compressive strength test. Other tests such as particle size distribution test for the fine aggregates and the pulverized polyethylene terephthalate (PET), slump tests were also carried out before concreting.

Regression equations depicting the compressive and flexural strength of the grade 25 concrete with both the PET content, fine aggregate, coarse aggregate, cement content, water content, and ages of curing were developed using a statistical package, Design-Expert Software 7.0.0. This software was adopted because it helps in designing the experiments before laboratory works were carried out. The responses (compressive and flexural strength of the PET concrete) on the independent variables (PET content, fine aggregate, coarse aggregate, cement content, water content, and ages of curing of the concrete) were studied. The experimental design was carried out for the PET concrete using Design-Expert software and this produced twenty-five (25) factorial designs as shown in Table 2. The value of 5 %–15 % by weight of the PET and 3 days–28 days of the curing duration were used to produce the PET concrete using the Design-Expert. The responses (compressive and flexural strengths of the PET concrete) were obtained as stated in Table 3. The significance of the model was evaluated using F-test while the coefficient of determination (R^2) was used to check the adequacy of the model.

3. Results and discussion

3.1. Particle size distribution test

Particle size distribution tests were carried out on the fine aggregate and the pulverized polyethylene terephthalate (PET) according to ASTM C136 (2014). The results are shown in Figure 1 and Figure 2.

3.2. Specific gravity test

Specific gravity was carried out on the samples according to ASTM C127 (2015) methodology. The average specific gravity of the fine aggregate was 2.54 while that of pulverized PET was 1.29 which shows that the pulverized PET is lighter than the fine aggregate.

3.3. Slump test

The test for the slump test for the optimum strength for 0 %, 5 %, 10 %, and 15 % are presented in Table 1 below.

Table 1 above shows the slump test for the optimum strength for 0 %, 5 %, 10 %, and 15%. It can be seen that an increase in PET content, causes a decrease in workability. One of the major reasons for having low workability may be due to the plastic in the mix not able to absorb the excess water thereby making a dry slump. This was collaborated by Baboo et al. (2012) and Nibudey et al. (2013).

3.4. Compressive strength and flexural strength test

Regression equations relating the compressive strength and flexural strength of concrete using different percentages of PET with fine aggregate, coarse aggregate, cement, water, and the curing duration were

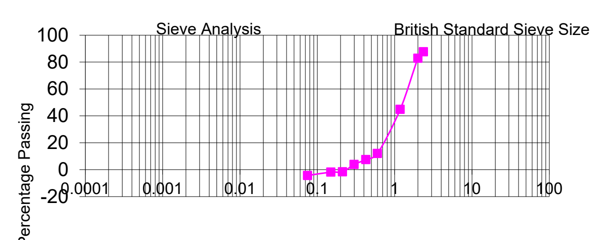

Figure 1. Particle size distribution test of fine aggregate.

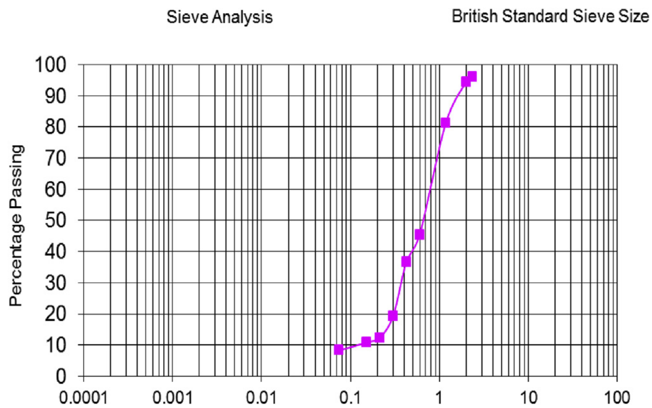

Figure 2. Particle size distribution test of the PET sample.

developed. Table 2 shows the factorial design for the PET concrete while Table 3 shows the factorial design and responses (compressive and flexural strengths) of the concrete using the different percentages of PET. The 5 % by weight of PET concrete had better results than 10 % by weight of PET concrete and 15 % by weight of PET concrete as shown in Figure 3 and Figure 4. Beyond the 5 % addition of PET, there was a progressive decrease in compressive strengths of the concrete as the percentages of PET increased in the blended concrete. It may be attributed to an increase in the surface area of the blended concrete.

The initial increase of compressive strength was collaborated by Ramadevi and Manju (2012) in their studies, which showed that there was an increase in the compressive strength, up to 2% replacement of PET in concrete. There was 20.4 % early flexural strength increase for 15% by weight of PET concrete over the control concrete at 3 days curing duration as shown in Figure 4.

The quadratic model for compressive strength of the PET concrete showed an R^2 value of 0.9792, which indicates that 97.92% of the variations in the compressive strength of the concrete are recorded by the independent variables (cement, fine aggregate, coarse aggregate, w/c ratios, % of PET and curing duration). More so, the results of the quadratic model for the flexural strength of the PET concrete show the R^2 of 0.5513. It reveals that 55.13 % of the variations in the flexural strength of the PET concrete are recorded by the independent variables (cement, fine aggregate, coarse aggregate, % of PET, w/c ratios, and curing duration).

4. Discussion

4.1. Effect of PET on the compressive strength of the blended concrete

The three-dimensional plot of percentages of PET and curing duration on the compressive strength of the blended concrete are shown in Figure 5. Increasing the days of curing and PET percentages increases the compressive strength of the blended concrete up to 5% of PET addition. Beyond 5% PET addition, the compressive strength of the blended concrete reduces. The initial increase of compressive strength may be due to the PET having proper bonding with the fine aggregate. This was

Table 1. Slump test for the pulverized PET and control concrete.

% Of pulverized PET	Slump (mm)
0	36
5	7
10	5
15	<5

Table 2. Experimental design matrix for the factorial design value for the PET concrete.

Std	Run	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
		A: Fine aggregates	B: Coarse aggregates	C: % Of PET	D: Days	E: Water	F: Cement
		Kg	Kg	%	Days		Kg
	1	9.875	18.330	0	28	3.276	6.427
	2	9.875	18.242	10	28	3.276	6.427
	3	9.298	17.254	0	3	3.276	6.427
	4	9.298	17.254	15	28	3.276	6.427
	5	9.643	17.254	15	3	3.276	6.427
	6	9.565	18.330	0	7	3.276	6.427
	7	9.553	17.254	0	28	3.276	6.427
	8	9.383	17.804	5	3	3.276	6.427
	9	9.875	17.552	5	7	3.276	6.427
	10	9.298	18.330	15	3	3.276	6.427
	11	9.298	17.287	15	7	3.276	6.427
	12	9.569	17.789	5	28	3.276	6.427
	13	9.565	18.330	10	7	3.276	6.427
	14	9.298	18.330	0	28	3.276	6.427
	15	9.875	17.254	15	28	3.276	6.427
	16	9.875	18.330	10	3	3.276	6.427
	17	9.298	17.254	0	3	3.276	6.427
	18	9.875	17.254	5	14	3.276	6.427
	19	9.298	18.330	10	14	3.276	6.427
	20	9.875	17.552	0	3	3.276	6.427
	21	9.875	17.000	15	14	3.276	6.427
	22	9.298	17.657	0	14	3.276	6.427
	23	9.554	18.330	15	28	3.276	6.427
	24	9.298	18.330	15	3	3.276	6.427
	25	9.875	18.330	10	3	3.276	6.427

Table 3. Experimental design matrix for the factorial design and responses for the blended concrete.

Std	Run	Factor 1 A: Fine aggregates Kg	Factor 2 B: Coarse aggregates Kg	Factor 3 C: % Of PET %	Factor 4 D: Days Days	Factor 5 E: Water	Factor 6 F: Cement Kg	Response 1 Compressive strength N/mm^2	Response 2 Flexural strength N/mm^2
	1	9.875	18.330	0	28	3.276	6.427	37.70	3.90
	2	9.875	18.242	10	28	3.276	6.427	28.36	3.44
	3	9.298	17.254	0	3	3.276	6.427	23.0	2.25
	4	9.298	17.254	15	28	3.276	6.427	27.98	2.91
	5	9.643	17.254	15	3	3.276	6.427	25.71	2.89
	6	9.565	18.330	0	7	3.276	6.427	25.30	3.00
	7	9.553	17.254	0	28	3.276	6.427	33.70	3.60
	8	9.383	17.804	5	3	3.276	6.427	27.90	2.60
	9	9.875	17.552	5	7	3.276	6.427	28.30	2.40
	10	9.298	18.330	15	3	3.276	6.427	22.8	2.30
	11	9.298	17.287	15	7	3.276	6.427	28.3	2.50
	12	9.569	17.789	5	28	3.276	6.427	33.4	3.60
	13	9.565	18.330	10	7	3.276	6.427	29.70	3.10
	14	9.298	18.330	0	28	3.276	6.427	31.0	3.60
	15	9.875	17.254	15	28	3.276	6.427	24.0	2.53
	16	9.875	18.330	10	3	3.276	6.427	21.0	2.18
	17	9.298	17.254	0	3	3.276	6.427	23.0	2.40
	18	9.875	17.254	5	14	3.276	6.427	29.2	2.50
	19	9.298	18.330	10	14	3.276	6.427	28.5	2.43
	20	9.875	17.552	0	3	3.276	6.427	26.70	2.85
	21	9.875	17.000	15	14	3.276	6.427	32.0	2.5
	22	9.298	17.657	0	14	3.276	6.427	29.0	3.00
	23	9.554	18.330	15	28	3.276	6.427	34.0	3.10
	24	9.298	18.330	15	3	3.276	6.427	23.7	2.30
	25	9.875	18.330	10	3	3.276	6.427	21.0	2.20

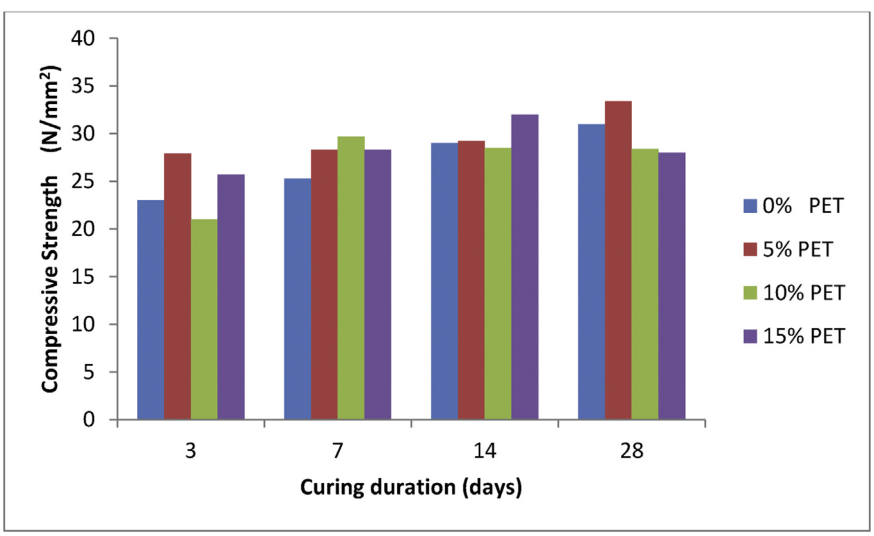

Figure 3. Relationship between compressive strength and percentages of PET.

collaborated by (Khilesh, 2014). The decrease of the compressive strength beyond 5 % may be due to the decrease in adhesive strength between the surface of the waste plastic and the cement paste (Baboo et al. (2012).

4.2. Effect of PET on the flexural strength of the blended concrete

The three-dimensional plot of percentages of PET and curing duration on the flexural strength of the blended concrete are shown in Figure 6. Increasing the curing duration decreases the flexural strength except at day 3 curing duration were the opposite happens. Baboo et al. (2012) attributed the decrease in the flexural strength to a decrease in adhesive strength between the surface of waste plastic and the cement paste. At 3 days curing duration, 15 % by weight of PET concrete had an increase of 20.4 % over the control concrete. The early increase of flexural strength at 3 days curing duration may be due to early hydration of the cement.

5. Conclusion

Based on the findings, the conclusion can be made thus:

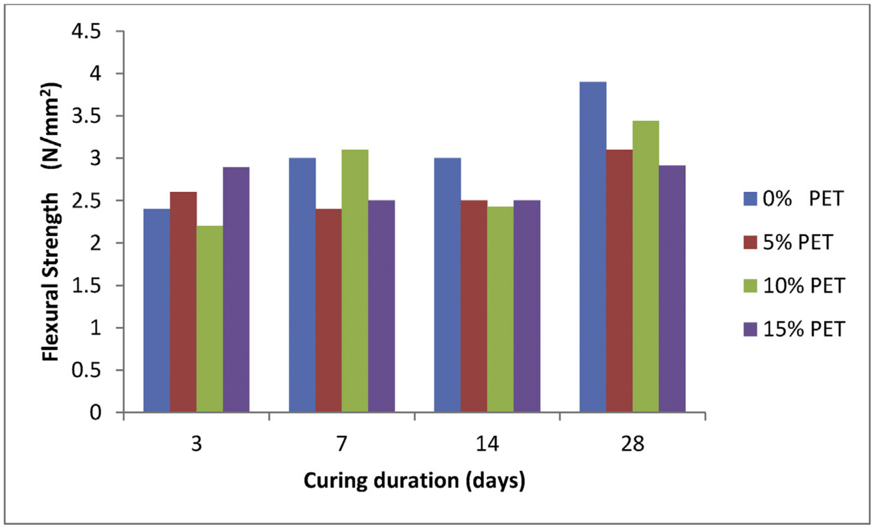

Figure 4. Relationship between flexural strength and percentages of PET.

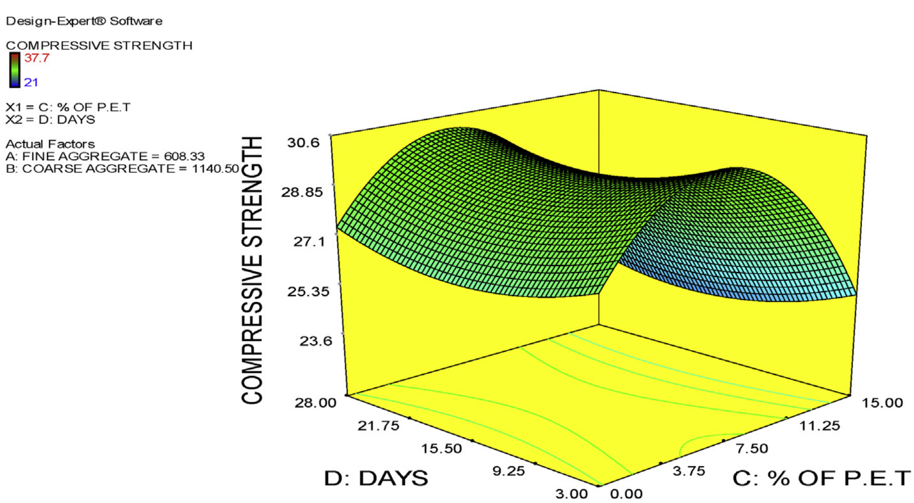

Figure 5. 3D Relationship between compressive strength and percentages of PET.

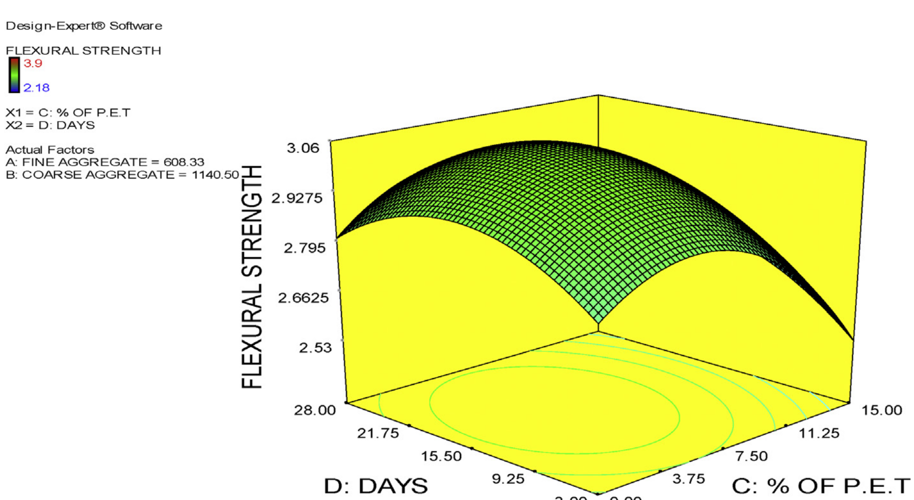

Figure 6. 3D Relationship between flexural strength and percentages of PET.

1. There was a decrease in workability as the PET contents increased in the concrete.
2. The compressive strength of the 5% by weight of PET concrete was the optimum compressive strength at 28 days of curing when it relates to the control concrete.
3. There was a progressive decrease in the flexural strength of the concrete as the PET percentage increased in the concrete.
4. The usage of 5% PET concrete in structural applications can be encouraged because of the highest compressive strength of 33.4 N/mm^2 that was achieved.
5. Some advantages could be achieved when using waste PET in concrete which may include disposal of wastes, energy-saving, and prevention of environmental pollution.

Declarations

Author contribution statement

Richie.I. Umasabor: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Samuel.C. Daniel: Performed the experiments; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Ahmad, M.S., 2014. Low-density polyethylene modified dense graded bituminous macadam. Int. J. Eng. Trends Technol. 16, 366–372.
Albano, C., Camacho, N., Hernandez, M., Matheus, A., Gutierrez, A., 2009. Influence of content and particle size of waste pet bottles on concrete behaviour at different w/c ratios. Waste Manag. 29 (10), 2707–2716.
ASTM C127, 2015. Standard test method for specific gravity and absorption of coarse aggregate. America Standard of Testing Materials International, West Conshohocken.
ASTM C136, 2014. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. ASTM International, WestConshohocken.
Baboo, R., Rushad, T., Bhavesh, K., Duggal, K., 2012. Study of waste plastic mix concrete with plasticizer. International Scholarly Research Network, volume20, pp. 2–5.
British Standard Institution BS 1881: Part 108, 1983. Methods of Making Test Cubes from Fresh concrete. London, United Kingdom.
BS EN 12390-3, 2019. Testing Hardened concrete: Compressive Strength of Test Specimens. British Standard Institution, London.
BS EN 12390-5, 2009. Testing Hardened concrete: Flexural Strength of Test Specimens. British Standard Institution London.
Choi, Y.W., Moon, D.J., Chumg, J.S., Cho, S.K., 2005. Effects of waste PET bottles aggregate on the properties of concrete. Cement Concr. Res. 35 (No. 4), 776–781.
Frigione, M., 2010. Recycling of PET bottles as fine aggregate in concrete. Waste Manag. 30 (6), 1101–1106. Elsevier.
Foti, D., 2013. Use of recycled waste pet bottles fibers for the reinforcement of concrete. Compos. Struct. 96, 396–404.
IS 456, 2000. Code of Practice-plain and Reinforced concrete.
IS 10262, 2009. Concrete Mix Proportioning – Guidelines.
Islam, A., Rahman, M., Ahmed, M., 2011. Polymer modified concrete: experience and potential for Bangladesh. Indian Concr. J. 55–57.
Khilesh, S., 2014. " study of strength property of concrete using waste plastics and steel fibers" department of civil engineering, jabalpur engineering college, jabalpur, India. Int. J. Eng. Sci. 3 (5), 9–11.
Kolhapure, B.K., Chavan, A., Irshad, A., Amar, B., Patel, H., 2018. Eco friendly concrete by partial replacement of sand by shredded pieces of PET plastic bottles. Int. Res. J. Eng. Tech. 5 (5), 1259–1263.
Nibudey, R.N., Nagarnaik, P.B., Parbat, D.K., Pande, A.M., 2013. Strength predictions of plastic fiber reinforced concrete (M30). Int. J. Eng. Res. Afr. 3 (1), 1818–1825.
Praveen, M., Shibi, V., Thomas, P., Eldho, V., 2013. recycled plastic as coarse aggregate for structural concrete. Int. J. Inn. Res. Sci. Eng. Techn. 2 (Issue 3).
Ramadevi, K., Manju, R., 2012. Experimental investigation on the properties of concrete with plastic PET (bottle) fibers as fine aggregates. Int. J. Emer. Tech. Adv. Eng. 2 (6), 42–46.
Sahmaran, M., Yaman, I.O., 2007. Hybrid fiber reinforced self-compacting concrete with high-volume coarse fly ash. Construct. Build. Mater. 21 (1), 150–156.
Wang, Z., Ma, Z., Li, L., 2016. Flow-induced crystallization of polymers: molecular and thermodynamic considerations. Macromolecules 49, 1505–1517.